

SPIO Acid Dissolution Kinetics with MR Susceptometry

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PURPOSE

Superparamagnetic iron oxides have very strong magnetic moments in MRI B₀ fields, making them efficient probes for cellular imaging or tissue contrast modification. Here, we show the feasibility of monitoring SPIO dissolution by acids using MR susceptometry.

MATERIAL AND METHODS

Experiments were performed at 1.5T. An interleaved multi-echo 2D spoiled gradient-echo sequence was used with the following parameters: FOV=40 cm, 128² matrix, slice-thickness=5 mm, BW=62.5 kHz with full-echo readouts, TR/TEs=7.7/1.7 2.7 3.7 4.7 5.7 ms, FA=30°, and a standard quadrature head coil. First, a reference acquisition was performed on a phantom comprised of plastic bottles filled with 78 mL of distilled water (Fig.1a). 20 slices covered the entire phantom. Then one water bottle was replaced by hydrochloride acid with different concentrations (19%, 15%, 9.75%) at room temperature. Feridex (7.8 μL) was finally added to the acid as a multiphase acquisition of a single slice in the middle of the bottle was started (one image repeated every 5 to 15 sec).

MR susceptometry was applied (1). For each phase, a field map was computed with linear regression on the signal phase evolution as a function of echo time. The reference phase map was then subtracted to obtain the phase effects relative to water. The observed field shifts were modeled by $\delta = \delta B_{z,local} / B_0 = \chi G \otimes D$, where χ is the solution susceptibility and $G \otimes D$ takes into account the convolution effects given by the geometry G of the bottle, convoluted with a dipole field $D = (3\cos^2(\theta) - 1) / 4\pi |r|^3$. From the multi-slice reference scan, the 3D model G was extracted as a 3D triangular surface mesh and used to simulate the field shifts for unit susceptibility $G \otimes D$ (2). The linear problem of susceptibility quantification was then solved for each time point using least squares, considering only the measured field with sufficient signal intensity (inside the water bottles).

RESULTS

Signal intensity within the bottle containing the SPIO-acid solution (Fig.1a) suffered from both strong T₂* decay and typical high diffusion edge enhancement. Consequently, the field inside this bottle was not measured accurately and excluded from the inversion. On the contrary, the field was accurately mapped in the water bottles (Fig.1b-e) which exhibited a familiar dipolar pattern. Susceptibility decreased as a function of time and was fairly well modeled by an exponential decay (Fig.2), starting from the expected value for ferumoxides at 2 mMol ~7.5 ppm and decreasing to ~1 ppm below water. Time constant values (Table 1) show a very high dependence on acid concentration. At the end of the reaction, the solution turned yellowish, as expected for FeCl₄⁻ production.

For the following reaction:

$\text{Fe}_2\text{O}_3 + 6\text{HCl} \longrightarrow 2\text{FeCl}_3 + 3\text{H}_2\text{O}$ a kinetic model for the case of acid excess like here would give a dependence to the power 6 of acid concentration, thus very sensitive to concentration, as observed. Assuming an evolution of the magnetic moment $\mu(t) = \mu_0 \exp(-t/T)$ with $1/T = k[\text{HCl}]^6$, then $k = 6.83 \cdot 10^{-7} \text{ s}^{-1} \text{ M}^{-6}$ describes the reaction in these conditions.

DISCUSSION AND CONCLUSION

Monitoring chemical reactions with MR based on susceptibility variations is feasible. Iron oxides contrast agent superparamagnetism allow very sensitive magnetic moment destruction measurements using MR. Furthermore, particle size and surface properties may affect reaction kinetics, as shows in basic chemical studies (3,4) and this kind of experiment could allow iron oxide characterization in metallurgy. In vivo, SPIO are uptaken by macrophages where they are destroyed. The superparamagnetism destruction process may be similar, based on nitric oxide reactions (5) and could be measured using this method. In addition to providing a new tool to measure reaction kinetics, this work may also be of interest for particle design optimization.

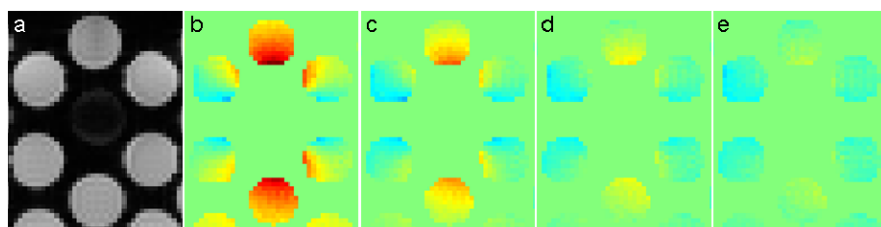


Fig. 1: Coronal signal intensity map obtained on the experiment with 19% HCl (a). The central bottle where the reaction occurs can barely be seen. Magnetic field maps restricted to the water proton probed outside the source at t=0, 20, 40, 60 s for the 19% experiment (b-e).

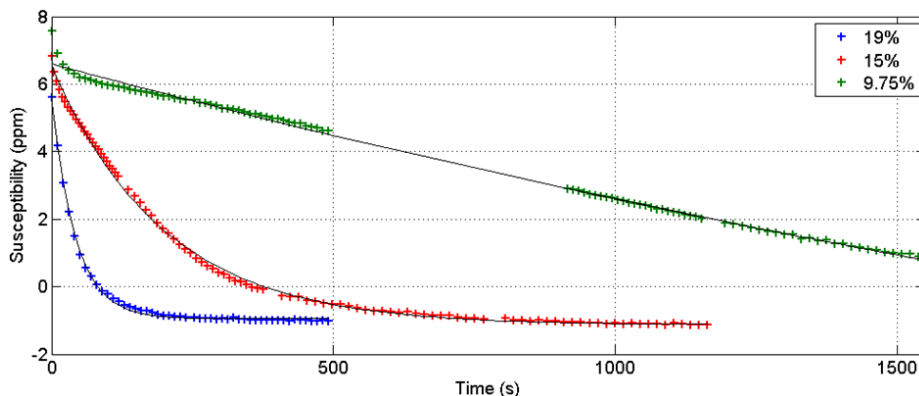


Fig. 2: Susceptibility evolution during the reaction and exponential fit.

HCl (M)	T (s)
5.7	42
4.4	196
2.8	1300

Table 1. Time constants, volumes converted to molarity

REFERENCES

- Holt et al., JMRI 1994, 4p809
- de Munck et al., IEEE TMI 15p620
- Chastukhin et al., Theoretical Foundations of Chemical Engineering, 2003 37p398
- Alafara et al., J Appl Sci Environ Mgt 2005, 9p15
- Fujii et al., MRI 2002, 20p271