Mapping the pore size distribution of a glass microcapillary array phantom using d-PFG MRI

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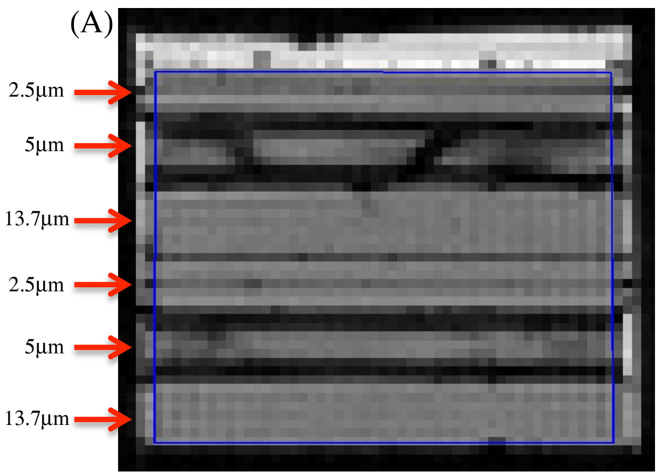
Introduction: Noninvasive characterization of porous media is critical to many scientific and technical fields. Estimation of an empirical pore size distribution (PSD) has been demonstrated with single pulsed-filed gradient (s-PFG) NMR in conjunction with solving an inverse linear problem.[1] In this case the solution depends on the degree of linear independence (degree of correlation between the different independent variables[2]) of the matrix that describes the set of linear equations. As the degree of multicollinearity rises, the solution becomes more ill-conditioned. Recently this linear approach was extended to include a second dimension in the parameter space using a double pulsed-field gradient (d-PFG) experiment.[3] This 2-D method was shown to reduce multicollinearity and thus improve the stability and reliability of the estimated empirical PSD.[3] Previously, this 2-D NMR method was performed on calibrated microcapillary PSD phantoms, resulting in accurate size distribution estimation.[4] Here we present the first MRI implementation of this 2-D method, and report the successful estimation of the PSD map using a well-characterized phantom.

Methods: The PSD phantom is a glass capillary array (GCA)[5] consisting of 3 different 2.5, 5, and 13.7 μm inner radii water-filled microcapillary wafers. d-PFG MRI experiments were performed on a 7T vertical-bore Bruker AVANCE III MR microimager. The acquisition parameters were: δ= 1.65ms, Δ=45ms, t_m=0, 8 diffusion gradients (G = 0-605 mTm^{-1}), 10 angles (φ = 0–π), TR=5s, TE= 7.75ms and spatial resolution = 0.242 X 0.242 X 1 mm^3. A total of 80 acquisitions were sufficient to obtain an accurate PSD in each voxel. The data was then fit to the 2-D linear PSD model.[3,4]

Results: A sagittal proton density MRI of the phantom is presented in Fig. 1A. Different wafer-packs with different sizes are indicated, and the region of interest (ROI) for the PSD estimation is marked in blue. The estimated PSD is shown in Fig. 1B. The theoretical radii were verified by fitting the signal to the corresponding ROIs. The theoretical volumetric fractions were calculated from proton density MRI. Each theoretical distribution (blue) is known and presented on top of the estimated distribution (red). No regularization process or assumptions on the parametric form of the PSD are used. The obtained radii and their fractions are in very good agreement with the theory.



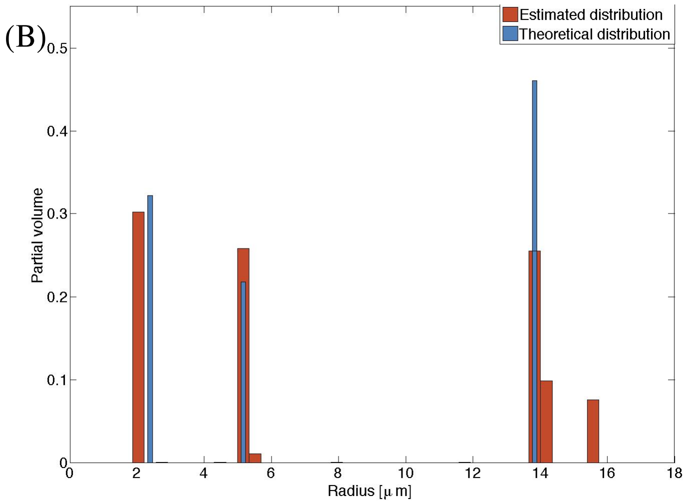


Fig. 1: (A) A proton density image of the GCA phantom. The different arrays are stacked and their size is indicated by red arrows. The ROI that was used to estimate the PSD is marked in blue. (B) The estimated (red) and theoretical (blue) PSD.

Reference: [1] K.G. Hollingsworth and M.L. Johns, J. Colloid Interface Sci., 258 (2003) 383-389. [2] D.E. Farrar and R.R. Glauber, Rev. Econ. Stat., 49 (1967) 92-107. [3] D. Benjamini et al., J. Chem. Phys., 137 (2012) 224201. [4] D. Benjamini and U. Nevo, J. Magn. Reson., 230 (2013) 198-204. [5] M.E. Komlosh et al., J. Magn. Reson., 208 (2011) 128-135