NMR T2 Response versus Roughness: A Numerical and Analytical Study

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Abstract. This work aims to develop an upscaling model using NMR T2 responses in smooth pore systems to evaluate T2 responses in rough pore systems. An upscaling factor is introduced as a function of a few dimensionless parameters (e.g. relative roughness, roughness density and shape factor) to characterize the surface-roughness effect. The proposed workflow has three main steps, including design and generation of synthetic 3D structures, simulation of NMR T2 responses, and modeling of roughness impact. Latin hypercube sampling is used to design rough pore structures with different relative roughness, roughness density and shape factor. Then random walk simulations are implemented and a robust T2 inversion algorithm is used to calculate NMR T2 responses in rough pore systems. We also evaluate the effective radii of smooth pores so that the corresponding T2 responses match up with NMR T2 responses in rough pore systems. Eventually, we establish a "value-to-value" model using machine learning to map the nonlinear relationship between the roughness parameters as input and the upscaling factor as output. The accuracy of the proposed model is validated by comparing NMR T2 responses with those directly simulated in rough pore systems. Numerical results show that the proposed model can estimate NMR T2 responses in rough pore systems using NMR T2 responses in smooth pore systems, with remarkable speedup around three orders of magnitude. We note that the generated surface roughness is supposed to have the characteristics of both diversity and representativeness. Missing either of them could damage the quality and reliability of the trained model. Previous work incorporating the roughness effect into surface relaxivity more likely violate the assumption of fast diffusion limit. Instead, the proposed model mitigates this limitation by introducing an upscaling factor, which incorporates multiple dimensionless parameters.