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Microscale simulations of NMR relaxation in porous media

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In petrophysical applications of nuclear magnetic resonance (NMR), the measured relaxation signals originate from the fluid filled pore space. Hence, in rocks or sediments the water content directly corresponds to the initial amplitude of the recorded NMR relaxation signals. The relaxation rate (longitudinal/transversal decay time T1, T2) is sensitive to pore sizes and physiochemical properties of rock-fluid interfaces (surface relaxivity), as well as the concentration of paramagnetic ions in the fluid phases (bulk relaxivity).
In the subproject A2 of the TR32 we aim at improving the basic understanding of these processes at the pore scale and thereby advancing the interpretation of NMR data by reducing the application of restrictive approximated interpretation schemes, e.g. for deriving pore size distributions, connectivity or permeability. In this respect we numerically simulate NMR relaxation data at the micro sale to study the impact of physical and hydrological parameters such as internal field gradients or pore connectivities on NMR signals. Joint numerical simulations of the NMR relaxation behavior (Bloch equations) in the presence of internal gradients (Ampere's law) and fluid flow (Navier-Stokes) on a pore scale dimension have been implemented in a finite element (FE) model using Comsol Multiphysics.
Processes governing the time and spatial behavior of the nuclear magnetization density in a porous medium are diffusion and surface interactions at the rock-fluid interface. Based on Fick's law of diffusive motion Brownstein and Tarr (1979) introduced differential equations that describe the relaxation behavior of the Spin magnetization in single isolated pores and derived analytical solutions for simple geometries, i.e. spherical, cylindrical and planar. However, by numerically solving these equations in a general way using a FE algorithm this approach can be applied to study and simulate coupled complex pore systems, e.g. derived from computer tomography (CT). In this respect substantial coupling effects in typical porous rocks can be observed at pore sizes about <1 µm, e.g. encountered in tight gas reservoir formations.
Internal magnetic field gradients in rocks arise due to susceptibility contrasts in pore fluid and rock matrix and depend on the magnetic field strength (Larmor frequency). To model the increased relaxation rate observed in CPMG measurements due to diffusive motion in a magnetic (internal) gradient field the simulations are coupled with calculations of spatial distribution of field gradients within the simulated fluid-matrix system according to Ampere's law. Contrary to common assumptions of a constant ratio between T1 and T2 in petrophysical NMR the CPMG simulations in the presence of internal gradients show a significant increase of T1/T2 ratios with decreasing pore sizes. This implies a shift of derived signal contributions to smaller pore sizes, e.g. <1 µm, from T2 NMR experiments, and thus an underestimation of derived permeabilities. µm
These simulations will also be compiled for multi-phase systems, e.g. water-air-oil, to study basic correlations between NMR and hydrological parameters of partially saturated rocks. This study was conducted within the framework of the Transregional Collaborative Research Centre 32, funded by the German Research Foundation (DFG).