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NMR Studies of Diffusion and Pore Size Distribution on Water-Containing Aquifer Rocks and Construction Materials

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1. Introduction

The structure and the mineralogy of the solid matrices of natural sedimentary rocks and many mineral-based construction materials are quite different. However, with respect to storage and transport properties of fluids (e.g. moisture, water, air, dissolved ions, pollutants, …) both types of materials have a common feature: They are porous materials with a large fraction of interconnected microscopically sized voids (pores), which store fluids and allow their transport over macroscopic dimensions.

The volume fraction of such voids (porosity), their size and surface-to-volume ratio, respectively, as well as the topology of the interconnected pores are characteristic parameters, which control the transport of fluids through the porous material. Nuclear magnetic resonance (NMR) provides different techniques to non-destructively measure these parameters. NMR relaxometry is able to quantitatively determine porosities and to qualitatively estimate trends in pore size distributions. NMR diffusometry yields information on the topology of the pore space by measuring the so-called tortuosity factor τ, which is obtained in this method by calculating the ratio of the self-diffusion coefficients of the bulk fluid (D_0) to its value in the pore space (D_{eff}) ($\tau = D_0 / D_{eff}$).

Although these NMR techniques are to a large extent independent of the actual structure and the mineralogy of the porous material, results of relaxometry and diffusometry may be misleading if strong magnetic susceptibility differences between the pore and matrix space of the porous material disturb the externally applied magnetic field and field gradients, respectively, necessary in these experiments. In this work we present low-field NMR relaxometry measurements on porous dolomite rocks and on fired-clay brick which clearly show disturbing influences of internal field distortions and compare different approaches of NMR diffusometry to reduce these influences. The aim is to unambiguously measure the self-diffusion coefficients of the pore fluids and tortuosities of the porous host materials.

2. Results

NMR relaxation time measurements at 0.21 T (9.1 MHz ^{1}H resonance frequency) with the CPMG sequence at different inter-echo spacing (0.1 ms $\leq 2\tau <$ 3.6 ms) on water-saturated fired-clay brick and dolomites indicate a much stronger τ^2-dependence of the transverse relaxation rate ($1/T_{2eff}$) than observed for a sample of bulk water (see Fig. 1). This is caused by strong dephasing of the transverse magnetization due to magnetic field distortions and diffusion on the length scale of the pore space in both types of materials. The high averaged contents of iron in the solid pore walls (4 % fired-clay brick; 1 % dolomite rock) are a possible mineralogical origin for these field distortions. Using the shortest possible inter-echo times, we show that even under such conditions, porosities and pore size distributions can be studied by CPMG NMR.

To minimize the influence of rapid dephasing of the transverse nuclear magnetization on NMR diffusion measurements, pulse sequences have to be used, in which the part of the nuclear magnetization that generates the relevant NMR signal is in the longitudinal direction during most of the measurement time. Using the fired-clay brick and the dolomite samples, we compared the results of two newly developed approaches [1,2]. The first technique is a stimulated echo sequence with variable constant gradients that had been originally developed for the fired-clay brick [1]. The diffusion coefficients and calculated tortuosity factors are compared with the results obtained by the pulsed field gradient NMR technique using the 13-interval sequence with [2] and without [3] additional suppression of variable internal field inhomogeneities by magic field gradient ratios.

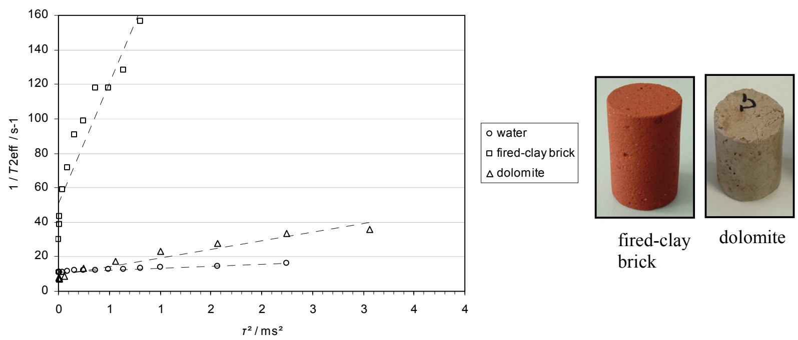

Fig. 1. Plot of the transverse relaxation rate against the echo time squared for a series of CPMG measurements using a low-field NMR spectrometer (9.1 MHz). Samples are bulk water, a water-saturated fired-clay brick and a dolomite rock (photographs).

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