Earth Field NMR of Porous Systems

M. Veevaete, V. Hormann, R. Goedecke, H.W. Fischer

Institute of Environmental Physics, University of Bremen, Germany

Earth Field NMR

Earth field NMR uses the globally available, homogeneous Earth magnetic field for detection.

The general model describing the relaxation of liquids filling pores [3]:

\[
\frac{1}{T_1} = \frac{1}{T_{1a}} + \frac{1}{T_{1b}} = \frac{1}{T_{1a}} + \frac{2\nu_0^2 \omega_0^2}{D} \frac{1}{T_1}\frac{1}{T_2} \frac{1}{T_2} = \frac{1}{T_{1a}} + \frac{1}{T_{1b}} + \frac{1}{T_{1c}}
\]

gives good results for \(T_1\) and can be simplified to:

\[
\frac{1}{T_1} = \frac{1}{T_{1a}} + \frac{1}{T_{1b}} + \frac{1}{T_{1c}}
\]

under the condition of surface limited relaxation.

Experimental setup

The Earth field NMR device has been developed in house based on the design presented in [2]. It is built in a way that it can be used in a normal laboratory environment with disturbances from electromagnetic fields and deterioration of the field homogeneity by steel in reinforced concrete or furniture. Self compensation against external alternating fields is achieved by a first order gradiometer construction. The temperature of the sample is kept constant (\(\pm 1^\circ\)C) by means of tempered air.

In a normal laboratory environment the Earth's magnetic field is disturbed. This disturbance is minimized by an appropriate location of the coil in the laboratory. By adjusting the current through three pairs of Maxwell coils the magnetic field gradient within the sample volume can be almost completely cancelled out and a very homogeneous field is obtained.

Results

Randomly packed glass beads

\(T_1\) and \(T_2\): Relaxation times for randomly packed glass beads were measured in function of the pore size at 20°C. Pore size, grain size and porosity are related by:

\[
\frac{d_{\text{pore}}}{d_{\text{grain}}} = \frac{1}{1 + 3 \frac{d_{\text{grain}}}{d_{\text{pore}}}}
\]

Figure 6: Relaxation time distribution of water in randomly packed glass beads

Figure 7: \(T_1\) in function of pore size and Larmor frequency. The lines represent the best fit using Eq. (3).

Sintered glass beads

\(T_1\) and \(T_2\) of sintered glass beads were also measured in function of the pore size at 20°C and analysed with a mono-exponential fit. The best fitting model fits very well to both \(T_1\) and \(T_2\) data.

Figure 8: Parameters for the surface limited relaxation model (Eq. 3) in function of the Larmor frequency with \(a=3\)

The values for the relaxivity are comparable with literature values [3, 4]. Although most models attribute the frequency dependence only to the surface contribution, one can see from Figure 10 and 11 that at low fields the bulk value is also frequency dependent:

\[
\frac{1}{T_1} = \frac{1}{T_{1a}} + \frac{1}{T_{1b}} + \frac{1}{T_{1c}}
\]

This was also found by [5].

Figure 9: Mono-exponential analysis of \(T_1\) in function of the pore size and frequency. The lines represent the best fit using Eq. (3).

First results from a bimodal porous system

The pore size distribution of a bimodal porous system containing 87% \(\text{Al}_2\text{O}_3\) and 13% \(\text{SiO}_2\) was analysed by \(T_2\) relaxometry and compared with Hg porosimetry results.

Figure 10: Mono-exponential analysis of \(T_1\) in function of the pore size and frequency. The lines represent the best fit using Eq. (3).

Figure 11: Frequency dependence of the relaxivity and \(T_{1b}\) according to Eq. 4 with \(a=3\)

A plot of the longitudinal relaxation dispersion from 3 kHz up to 3 MHz shows that at about 1 MHz the relaxation rates reaches its minimum. At a Larmor frequency of a few kHz \(R_2\) is still significantly larger than \(R_1\).

Figure 12: \(R_1\) dispersion (○) and \(R_2\) (□) in the Earth's magnetic field for sintered glass beads of various pore sizes

References