T_1 or T_2 – A simple choice?

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SUMMARY

It is well known that both T1 and T2 relaxation time compared with FID measurements provide superior information to derive hydraulic properties as they are less affected by magnetic gradients. Within the last years, measurement sequences and techniques have been developed that allow for estimating both parameter. However, one may ask which one to take?

In this abstract advantages and disadvantages in the context of determining the water content and the relaxation time from measured data are discussed to help making decisions.

Key words: T1 relaxation time, T2 relaxation time, spin echo, signal-to-noise

INTRODUCTION

Surface NMR is well known as a method with direct sensitivity to subsurface water and therefore used to derive the distribution of water content in the subsurface. In order to obtain a water response measuring the free induction decay (FID) can be sufficient, however, in addition to detecting water, the interpretation of NMR relaxation time allows for estimating pore-size information.

It is reported (e.g. Grunewald et al., 2011) that the FID decay time T2* is highly sensitive to magnetic field gradients and T1 or T2 relaxation time is much more appropriate for estimating hydraulic conductivities as they are less affected by magnetic gradients. Within the last years, measurement sequences and techniques have been developed that allow for estimating both parameter (Legchenko et al. 2010, Walbrecker et al., 2011, Müller-Petke et al., 2013, Grunewald and Walsh, 2014).

In this abstract advantages and disadvantages in the context of determining the water content and the relaxation time parameter from measured data are discussed.

T1 versus T2 kernel

The state-of-the-art T1 kernel has been presented by Walbrecker et al. (2011) using a phase-cycling scheme in order to suppress unwanted FID components. The T1 kernel is basically an FID kernel including an additional term that contains the distribution of the T1 relaxation time with depth. Consequently the T1 kernel depends on T1 and any inversion scheme is non-linear. The state-of-the-art T2 kernel is given by Legchenko et al. (2010) and the measurement scheme has been extended by Grunewald et al. (2014) to supress unwanted impact of FID components. The T2 kernel is independent of T2 and therefore the inversion is not necessarily non-linear.

Figure 1 shows a T1 and T2 kernel. The T1 kernel is calculated for the second pulse at 10 s, i.e. matches the FID kernel, allowing for comparison to the T2 kernel (i.e. both kernel show the maximum of their sensitivity) in terms of sensitivity and structure. The differences are remarkable. The T1 kernel shows higher sensitivity. The T2 kernel shows a smaller sensitive area. Both properties indicate that the detected signal amplitude for T2 is lower compared to T1.

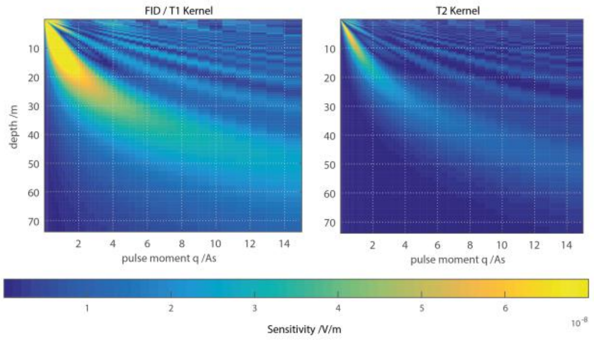

Figure 1. T1 and T2 Kernel calculated for a 50m diameter circular loop, a resistive half space, earth magnetic field is 48000 nT and 60 degree inclination.

SYNTHETIC SIGNALS

In order to evaluate measured signals, a simulation is carried out using the model parameter as in Table 1, i.e. a 4 layer case with an unsaturated zone, two aquifer and an aquiclude. The T2* relaxation time is chosen short to account for the case of magnetic gradients but long enough to be detectable. T1 and T2 relaxation time is equal. The data is contaminated with 10 nV of Gaussian noise, thus representing good noise conditions. Three echos for T2 and three secondary FIDs for T1 at 0.1 s, 0.3 s and 0.6 s are simulated in addition to a standard FID.

Layer Thickness	Water Content / m^3/m^3	Relaxation time T_2^* /s	Relaxation time $T_{1,2}$ /s
5	0.05	20	50
10	0.35	50	300
15	0.25	50	100
~	0.45	3	5

Table 1. Model parameter

The signals at a pulse moment of 1 As (the one showing highest amplitudes) confirm the kernel interpretation. While both primary and secondary FIDs show good data quality, the signal amplitude of the echoes is lower by approximately a factor of 2 to 3 leading to lower SNR for the T2 data.

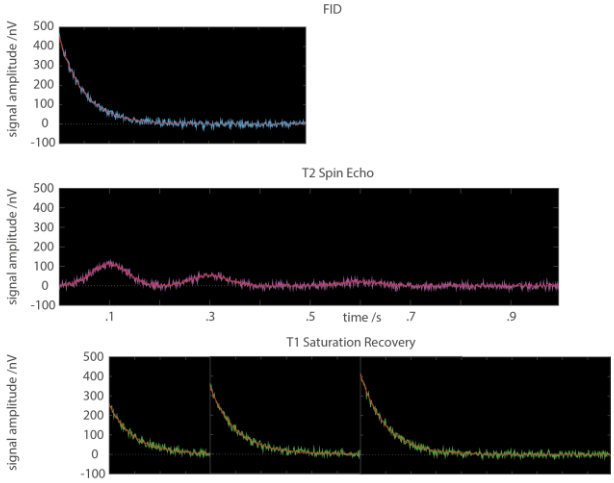

Figure 2. Simulation of FID, T1 and T2 data based on the kernel as in Figure 1 at a pulse moment of 1 As and modelling parameter as in Table 1.

INVERSION

Data processing and inversion has been carried out using MRSMATLAB (Müller-Petke et al., 2015). In general the model parameters (Table 1) can be extracted by all approaches. The highest regularisation is chosen that still satisfies the data within the error bounds. Due to the lower SNR and consequently lower resolution, the results from the T2 data is slightly smoother compared to the T1/FID results.

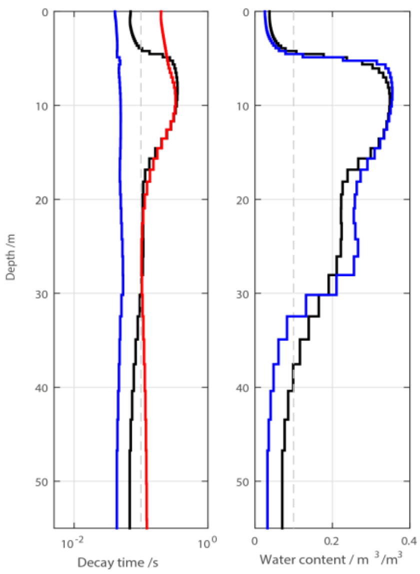

Figure 3. Inversion results (water content and relaxation time) for FID (blue), T1 (red) and T2 (black) data for modelling parameter as in Table 1.

DISCUSSION

Besides this simple simulation with the outcome of lower SNR using the spin echoes a few more things are to be considered.

Survey time

Unlike T1 measurements, where every secondary FID needs to be measured independently, T2 measurements can contain several echoes (Grunewald and Walsh, 2013). Thus, the lower signal amplitude may be compensated by higher stacking rates to end up with equal or even higher SNR as for T1 in equal measurements times.

Penetration depth

Both, T1 and T2 need at least two pulses. Consequently, the maximum pulse moment using the single pulse FID is typically higher. If multi-echo schemes are used, the maximum pulse moment further decreases and consequently lowering the penetration depth.

Detectability

The key advantage of the spin echo method is the detectability of NMR signals if the T2* time is very short but T2 is long. If T2* is too short to be detected, T1 measurements are impossible.

REFERENCES

Grunewald, E. and Knight, R., 2011, The effect of pore size and magnetic susceptibility on the surface NMR relaxation parameter T2*. Near Surface Geophysics, 9 (2), 169-178.

Grunewald, E. and Walsh, D., 2013, Multiecho scheme advances surface NMR for aquifer characterization. Geophysical Research Letters, 40 (24), 6346-6350.

Grunewald, E., Knight, R. and Walsh, D., 2014, Advancement and validation of surface nuclear magnetic resonance spin-echo measurements of T2: Geophysics, 79 (2), EN15-EN23.

Legchenko, A., Vouillamoz, J. M. and Roy, J., 2010, Application of the magnetic resonance sounding method to the investigation of aquifers in the presence of magnetic materials: Geophysics, 75 , L91-L100.

Müller-Petke, M., Walbrecker, J. O. and Knight, R. J., 2013, The inversion of surface-NMR T1 data for improved aquifer characterization: Geophysics, 78 (6), EN83-EN94.

Müller-Petke, M., Braun, M., Costabel, S., Hertrich, M. and Walbrecker, J., 2015: MRSMATLAB – processing, modelling and inversion of MRS data: MRS2015 – 6th International Workshop on Magnetic Resonance, Aarhus, Denmark.

Walbrecker, J. O., Hertrich, M., Lehmann-Horn, J. A. and Green, A. G., 2011b, Estimating the longitudinal relaxation time T1 in surface NMR: Geophysics, SEG, 76 (2), F111-F12.