

● Short Communication

THE EFFECT OF WAIT TIME ON T_2 DISTRIBUTIONS FROM NMR EXPERIMENTS

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Nuclear magnetic resonance (NMR) relaxation curves for both T_1 and T_2 on two brine-saturated core plugs have been measured at 1 MHz. T_2 distributions were extracted from Carr–Purcell–Meiboom–Gill (CPMG) measurements using different wait times between consecutive echo sequences. The analysis was performed with both a limited number of exponentials and a continuous B-spline basis. The distributions depend strongly on wait time. The distributions were generally restored to the true distributions when a wait time correction was applied.
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Relaxation and diffusion measurements from nuclear magnetic resonance logging (NMRL) are widely used to measure pore size distributions in oil reservoirs. Due to the cost of running NMRL tools downhole, the logging procedure has to be time efficient. Most logging tools use the Carr–Purcell–Meiboom–Gill (CPMG) method to measure the spin-spin relaxation time T_2 . The observed decay signal comes from contributions of fluids in all the pores in the porous medium. This will lead to a distribution of T_2 values, each component representing a specific pore size. In the fast diffusion limit, the observed spin-spin magnetization curve may be written as a sum of monoexponentials, each representing a certain pore size, called a bin:

$$M(t) = M_0 \sum_{i=1}^N a_i \exp(-t/T_{2i}), \quad (1)$$

where a_i is the fraction of relaxing spins with relaxation time T_{2i} . We assume that diffusion does not influence the relaxation curve. When CPMG echo trains are used repeatedly in T_2 measurements to improve data statistics, the wait time, T_R , between consecutive echo trains must be long enough for the magnetization M_0 to fully recover along the direction of the static magnetic field. This is well achieved if $T_R > 5T_1$. In many reservoirs, however, T_1 for water may be on the order of seconds. If several

hundred echo trains are needed to obtain acceptable statistics, the total measurement time for each tool position may be very long, in certain cases on the order of 1 h.

If the magnetization vector is not fully recovered along the field axis before the next echo train is started, it will be attenuated by a factor:

$$f(T_R) = 1 - \exp(-T_R/T_{1i}). \quad (2)$$

The CPMG echo amplitude decay in Eq. (1) can be corrected by this factor, and we may write:

$$M(t) = M_0 \sum_{i=1}^N a_i [1 - \exp(-T_R/T_{1i})] \exp(-t/T_{2i}). \quad (3)$$

Using an experimentally determined $M(t)$ curve from a CPMG echo train experiment, the distribution coefficients a_i may be extracted from Eq. (3) by a numerical fitting procedure. The resulting T_{2i} spectrum represents the pore size distribution. To perform the wait time correction in Eq. (3), a relation between T_1 and T_2 is necessary. Kleinberg et al.¹ have studied the T_1 and T_2 distributions from a typical sandstone at 2 MHz. They found the two distributions to have approximately the same shape, but were displaced from one another by a multiplier $\beta = T_1/T_2$. Measuring this ratio on a variety of sandstone and carbonates, they found β ranging from 1.0–2.6, with a mean of 1.74.

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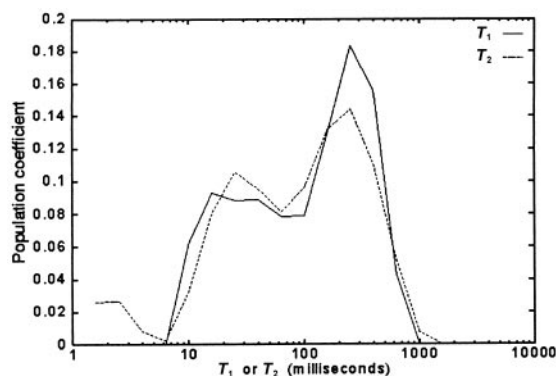


Fig. 1. Comparison of T_1 distribution and T_2 distribution (with $T_R = 5.0$ s) for the IAA sample.

We have measured both T_1 (inversion recovery) and T_2 (CPMG echo trains) on two 1-in.-diameter brine-saturated sandstone core plugs. Both measurements were performed at 1 MHz. The sample labeled IAA had a porosity of 23.5% and an air permeability of 9.8 md; the porosity of the IAB sample was 25.8%, and the air permeability was 419 md. The number of echos used in the CPMG measurements was 650, with an echo spacing of $2\tau = 1$ ms. The wait time T_R between consecutive echo trains ranged from 0.15–5.0 s. The longest wait time is expected to be well above the time necessary for the magnetization to recover along the field axis.

T_1 and T_2 distributions were extracted from the magnetization curves both by fitting a polyexponential ($n = 18$) using a curvature-smoothing method (K.-J. Dunn, Chevron Petroleum Technology, personal communication, 1996) and by solving the inverse problem in Eq. (1) using B-splines and a continuous basis.²

In Fig. 1 we show a comparison of T_1 and T_2 for the IAA sample. The two distributions have approximately

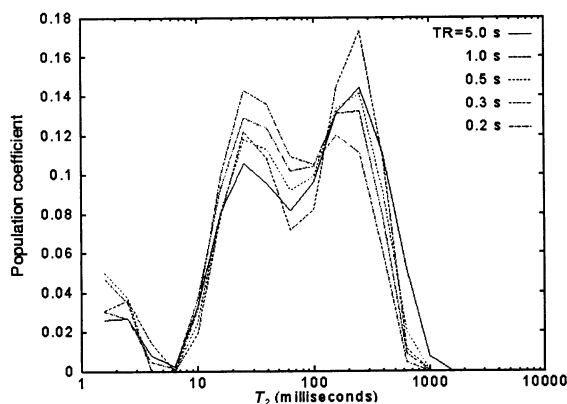


Fig. 2. Uncorrected T_2 distributions for different wait times T_R ; IAA sample.

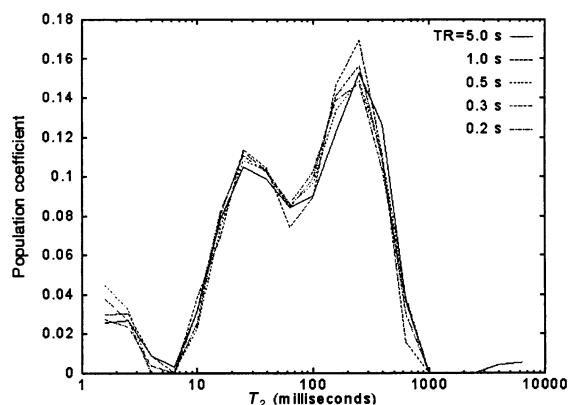


Fig. 3. Corrected T_2 distributions for different wait times T_R using a correction factor $\beta = 1.0$.

the same shape, but are displaced from one another by a factor $\beta = T_1/T_2$. For the IAA sample this factor is found to be 1.4, and for the IAB sample it is 1.3. Both numbers are consistent with Kleinberg's results.¹

T_2 distributions resulting from Eq. (1) for different wait times are shown in Fig. 2. The distributions are strongly wait time dependent. The effect of short wait times is quite apparent, with an underestimation of long T_2 values and overestimation of short T_2 values as the wait time is decreased. The curve corresponding to the longest wait time, $T_R = 5.0$ s, may be considered to be the true distribution.

In Fig. 3, the result of applying the wait time correction, as given in Eq. (3), is shown. A correction factor $\beta = 1.0$ ($T_1 = T_2$) was used with the curvature-smoothing method. The distributions resulting from different wait times become strikingly more similar, even for low T_2 values where the correction factor is close to unity. Apparently, the effect of the correction factor at high T_2 values is to change the distribution also at low T_2 values. Using $\beta = 1.4$, does not alter the result substantially, but a value close to 1.0 seems to give the best result. We have also performed the same wait time correction, but with B-splines to represent the basis in Eq. (3). The distributions recorded with short wait times are restored to the true distribution, represented by $T_R \gg T_1$ with this method also.

Hence, we have shown that it may be possible to correct for short wait times, $T_R < 5T_1$, to speed up a logging process that is based on CPMG measurements of T_2 .

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