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Geoscientific Instrumentation Methods and Data Systems
Discussions

Interactive comment on "Optimization of CPMG sequences for NMR borehole measurements" *by* M. Ronczka and M. Müller-Petke

Anonymous Referee #1

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The authors have revised the paper "Optimization of CPMG sequences for NMR borehole measurements", however, some issues still remain. In particular, although the use of english in this version is better than the previous version, many errors still remain. I was not able to correct all the errors but I hope the ones that I have caught, listed below, will help the authors to improve the manuscript. Additionally, in their revision, the authors have not yet referred to other modified CPMG pulse sequence that have been used in borehole logging to collect NMR measurements. In the specific comments below I have listed some references that the authors might want to look at as they revise this version of the paper. Finally, it is not clear to me how collecting a measurement with a variable echo time gives the same information as collecting multiple CPMG pulse sequences at multiple echo times - some justification

by the authors to clarify this point is warranted. By collecting CPMG measurements at multiple echo times one could determine the magnetic field gradient (last term in equation (4) or alternatively, determine if their are magnetic susceptibility differences between the saturating fluid and the grains. By collecting a single CPMG measurement at multiple echo times it is not clear to me how this same information could be obtained. Below I have provided a list of specific concerns I have about the manuscript.

Page 508
Abstract
Translation mistake in first line (Nuclear)
Change 'Especially" to "In particular"
Here and other locations in the paper: the time constant 'τ' usually refers to half the echo time. Use 't_E' or '2τ' to refer to the echo spacing.
Line 10: I would say that it is 'state of the art' to collect 2D NMR profiles (i.e. D-T2 or T1-T2) rather than just CPMG pulse sequences.
Line 18 – "The results show that" (not the results are showing).

Page 509
Line 16 – should be "Each of these pulses"
Line 18 – clarify what you mean by "it is common to conduct at least two different CPMG sequences". Presumably the authors mean that to obtain information about magnetic effects of minerals it is necessary to collect measurements at two echo-times. I'm not sure that you could say that it is common to collect measurements at two echo times.
Line 25 – Besides should be "in addition to".
Line 26: NMR is now used for near surface investigations so this information is out of date.

Page 510
Line 3 – poor word choice: “is not interoperable” should be “is not interchangeable”
Line 5 – the energy use does not limit the tool size - Vista Clara has a tool that fits in boreholes with two inch diameters. A different reason for a more efficient pulse sequence would be that collecting measurements at multiple echo times currently takes a very long time. Particularly if the borehole is long or the water content is low.

Page 511:
Line 14: This sentence is incorrect. All effects that lead to T2 relaxation are not just magnetic field gradients. For instance, bulk water in a homogenous field still exhibits T2 relaxation.
“These can be large scaled” is awkward, a better way to phrase this sentence would be “These inhomogeneities can be on the macro-scale” or (correspondingly refer to “small-scale” as the “pore-scale”).
Line 23 – T2* is mentioned here without any introduction. Presumably the authors mean to be referring to T2, right? If not, some introduction should be given for T2* and equation (1) and the following discussion should be changed to reflect the reference to T2*.
Line 24 – Equation 2 is specific for water (or oil) saturated porous media. This information should be clarified somewhere.
Line 25 - Coates et al. 1999 is not the best reference here. I suggest using Kleinberg and Horsfield (1990).

Page 512
Section 2.2
Line 6 – all influences of macroscopic magnetic gradients are not reversible by using the CPMG pulse sequence. For a water saturated sample the pathway taken by a single proton due to diffusion of that proton (and thus the magnetic field experienced

by the proton) during the course of the NMR measurement is not reversible (as stated by the authors in the following sentences).
Line 9 – trough should be through.
Line 15 (equation 3). The authors are using the symbol “τ” here to refer to $\frac{1}{2}$ the echo spacing – this is not the same as has previously been used in this paper. I would suggest that the authors consistently use $t_E(=2\tau)$ and amend equation 3 to reflect this change.
Line 24 – “is to large” should be “is too large”.
I would suggest switching the order of the two sentences at the end of this page.

Page 513:
Line 10 – change “S [m^2] the surface” to “S [m^2] the surface area”.
Line 11 – it is implied here that the authors are talking about a single pore. Is this the case or are they referring to the entire pore space? Please clarify and make the paragraph consistent.
Line 21 – verb-noun agreement (there are others throughout the documents so the authors will want to carefully review). “several refocusing pulses which flip” (not flips).
Line 24 – this is the correct use of the symbol tau although it is inconsistent with previous uses.

Page 514
Lines 5 to 12. It would be worthwhile to note that the last term in equation 4 can be quantified if measurements are collected at multiple echo-times.

The authors should summarize how their pulse sequence is different than other modified CPMG pulse sequences. Some references they should look into are Song (2003, 2007), Hurlimann and Venkataramanan (2002).

The sentence starting on line 14 should be in the same paragraph as the sentence starting on line 17.

Line 21 to Line 24: I find this confusing and am not sure what the authors mean here. Some clarification is necessary. Specifically how is the third sentence here not just repetition of the first sentence?

Line 28 minimal and maximal should be minimum and maximum.

Page 515:
It is not just sufficient to say "starting with the lowest possible τ_{min}, the fast decaying components are sampled as accurately as possible. . .". Some explanation of the spin dynamics occurring are necessary. For instance, in the CPMG pulse sequence, the pulse gets refocused and results in an echo due to the symmetry of the times used. If the echo time is changed from pulse to pulse, this refocusing could potentially be lost. The authors should comment on how the echo evolves in this new pulse sequence.

Section 4.1 Equation 1 is not really sufficient to show the entire pulse evolution (i.e. the jus the maximum of the echoes) – the authors should consider doing a synthetic study in which they start with the modified bloch torrey equations.

Page 517
Sentence starting at the end of line 25 – this sentence does not make sense to me.

Page 518:
Line 6 – the authors state that Coates gives three factors that influence the magnetic

gradient but subsequently only list two. They should list the third to be consistent.
The MRIL tool is not defined — I'm not sure what the authors mean by 'here' as this tool is not used in this paper.

Page 519:
First two sentence in section 5. I'm not sure what the authors are trying to say here. How is the shortened acquisition time an influence on the estimate T2 decay time? The authors should rephrase this paragraph so that their intended meaning is clear.

Line 20 (here and other places). The word "granulate" is a verb, the authors need a noun describing their samples and so it would be clearer to say "granular material".

Page 520:
Line 6: "the samples were weighed" (not weighted).
Line 7: "To appraise a possible evaporation" should be "to determine if evaporation occurred during . . ."
Line 18-19: "The amount of echoes" should be "The number of echoes"
Line 27: "spectra is increasing from top to bottom" should be "spectra increases from top to bottom".

In some of the numerical simulations a gradient was used, however, no gradient was used in the laboratory measurements some discussion on the effect that adding the gradient (and possibly measurements in the presence of the gradient) would improve the paper.

Page 522
Section 5.2.3 is inaccurately named since the author discusses both the granular

material and the glass bead samples here.

Page 523:
Line 23 – by saying "to compensate (for) this" the authors are implying that they can change the samples to make up the difference. I think their intention here is to explain the difference. I suggest they rephrase the sentence as "The similarity between these measurements could be explained by a difference in the surface relaxivity and/or internal magnetic field gradients." I note that collecting measurements at multiple echo times would be a way to determine if their is any decay due to internal magnetic field gradients. That said though, the authors are assuming S/V = 1/d (where d is the grain size) and so they are expecting that S/V would be different for each sample. While it makes sense that these samples likely have different rho values, I would argue that they could have similar S/V values (the glass beads have smooth surfaces and are round whereas the grains have rough surfaces and are angular).

Page 524, line 13 – τ_{max} should be between 1000 and 2500 us (not less than both 1000 us and 2500 us).

Table 1: The range of sizes used for the glass beads do not correspond to what is shown in the subsequent figures

Table 3: It might be helpful to the reader of the sample description was "small glass beads", "medium glass beads", "coarse glass beads" to help differentiate these samples from the granular materials. This also applies to the text.

Figures 4 through 8. The legends on these figures are difficult to read.

References:
Hurlimann and Venkataramanan, 2002, Quantitative Measurement of Two-Dimensional Distribution Functions of Diffusion and Relaxation in Grossly Inhomogeneous Fields: Journal of Magnetic Resonance, 157 31-42.

Kleinberg and Horsfield, 1990, Transverse Relaxation Processes in Porous Sedimentary Rock: Journal of Magnetic Resonance, 88, 9-19.

Song, 2003, Using Internal Magnetic Fields to Obtain Pore Size Distributions of Porous Media: Concepts in Magnetic Resonance Part A, 18A(2), 97-110.

Song, 2007, Novel NMR techniques for porous media research: Cement and Concrete Research, 27, 325-328.

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