NUCLEAR MAGNETIC RESONANCE SIGNALS FITTING METHOD USING 'DISTRIBUTION' PROGRAM

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1. Introduction

The result of NMR determination most commonly used in petrophysics is the distribution of T_2 transverse relaxation time of hydrogen nuclei. Fitting theoretical curves into measured signals is the most important step in NMR signals analysis. The main analysis object was to differentiate between the movable medium, capillary water and water bound in clay minerals. In literature we can find standard T_2 cut-offs which separate rock pore space. For sandstones this value are 3 ms and 33 ms and for carbonates 3 ms and 92 ms [1]. Unfortunately, standard cut-offs value often are different then real value for specific rock type. '*Distribution*' program was developed for dividing rocks with respect to the type of pore space, on the basis individual T_2 cut-offs. This method of processing NMR data was based on special fitting of several selected exponents (Gaussian or Weibull distribution). We measured and interpreted a several dozen samples. In this paper we present only an examples from Polish lowland and the Western Carpathians.

2. NMR method

The NMR measurement used in petrophysics consists in recording the relaxation times for hydrogen nuclei. The mechanism of relaxation depends on the type of relaxation surface, pore sizes, and the communication between pores, mobility of fluids saturation the volume of pore space, and diffusion of molecules.

Continuous T_2 relaxation times distribution is directly connected with pore size distribution in measured sample. In multiphase systems, where media of diverse qualities fill the complex rock porous space, the spin-spin relaxation curve can be presented as a sum of components, of which any one can be characterized by the relaxation time T_2. Individual relaxation times T_2 can be determined by an appropriate decomposition of the function *M(t).*

(1) $$M(t) = \sum_{i=1}^{n} M_{0i} \exp(-t / T_{2i}),$$ where: *n* is the number of exponents.

3. New methodology

In probability theory, the Gaussian distribution is a continuous probability distribution that has a bell-shaped probability density function:

(2) $$f(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2} \right),$$ where: μ is the mean (location of the peak) and σ is the standard deviation.

Weibull distribution is a co continuous probability distribution that has a probability density function:

(3) $$f(x) = \lambda p \cdot (\lambda x)^{p-1} e^{-(\lambda x)^p}$$; where: λ - scale parameter, p - shape parameter.

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NMR signal analysis was performed using program '*Distribution'.* Using this program we can select number of exponents, type of distribution (Gaussian (2) of Weibull (3)) and individually find the limits between different pore type components [2].

Program '*Distribution'* is based on guidelines:

1. fitting distribution (Gaussian or Weibull) into measured signal can be done in a several number of segments, maximum 8; in each segments Gaussian or Weibull distribution is fitting according to equations (2) and (3).
2. cumulative curve and cumulative error are calculated
3. we trying to find minimum fitting error

Relative mean squared error is calculated in whole signal and in each segment:

(4) $s^* = \left(\frac{1}{N} \sum_{i=1}^{N} (y_e - y_t)^2 \right)^{0,5}$ where: y_e – estimated value, y_t - theoretical value.

4. Material and analysis

In total data set clastic and carbonate rocks were used obtained from various litho-stratigraphic units, and collected in wells situated within the Polish lowland, Carpathian Depression and the Western Carpathians. We measured and interpreted a several dozen samples. In this paper we present only an examples [3].

On the figures 1 and 2 green line is the cumulative results of fitting, blue lines are the results of fitting in each modes (exponents) and red line is the recorded signal.

Sample nr 1 (Fig. 1) is a sandstone obtained from the Rotliegendes (P1) formations within the fore-Sudetic monocline with a high value of total porosity (13.6%). In all samples from this group the best fit Gaussian function to measured T2 distributions was observed to 3 exponents (the lowest error value). T2 cut-offs for whole sandstones data set appointed by authors (6 and 49 ms) differ from standard T2 cut-offs.

Sample nr 2 (Fig.2) is a limestones from wells in the Western Carpathians. Analysis of pore distribution is more difficult and complex in carbonates. In data set the best fit Gaussian function to measured T2 distributions was observed to 4 exponents (the lowest error value). The last group probably is connected with cracks, which was observed for this group of samples. T2 cut-offs for whole limestones data set appointed by authors (7.7, 87 i 257 ms)differ from standard T2 cut-offs

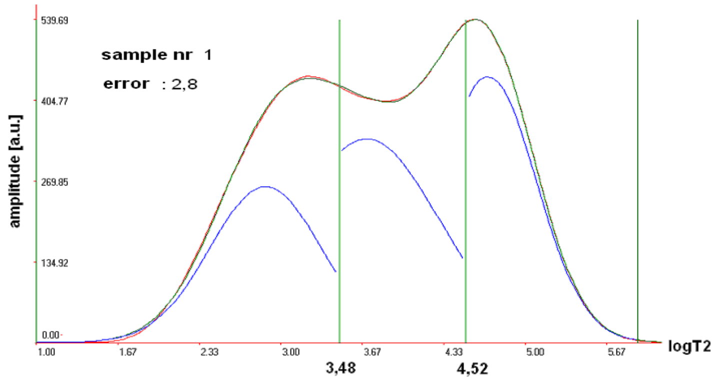

Figure 1a.

3-modal Gaussian distribution fitting using standard T2 cut-offs for sandstones: 3ms and 33 ms, sample 1

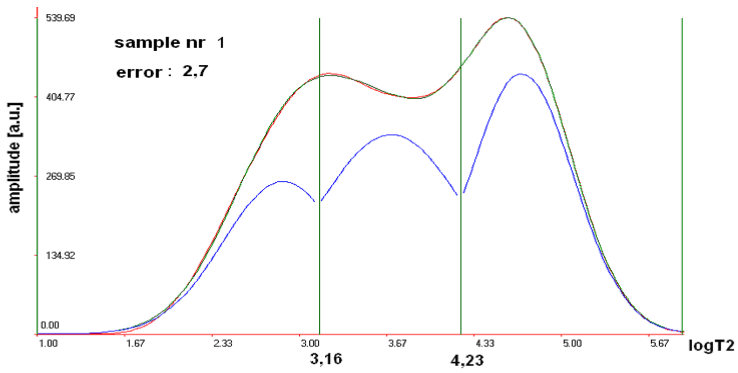

Figure. 1b. 3-modal Gaussian distribution fitting using individual T2 cut-offs: 1,5ms and 17ms, sample 1, sandstone

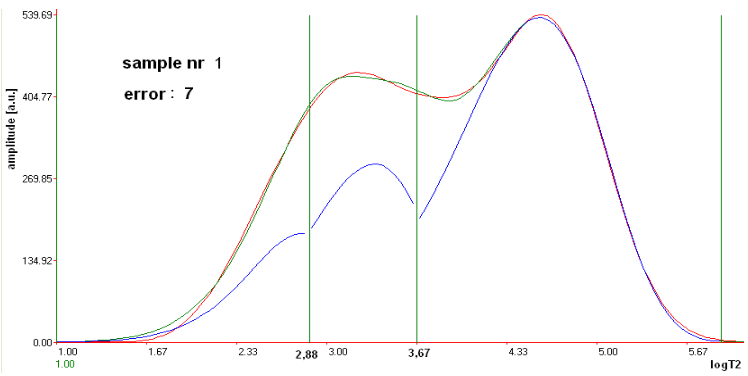

Figure. 1c. 3-modal Weibull distribution fitting using individual T2 cut-offs: 0,6 ms and 6ms, sample 1, sandstone

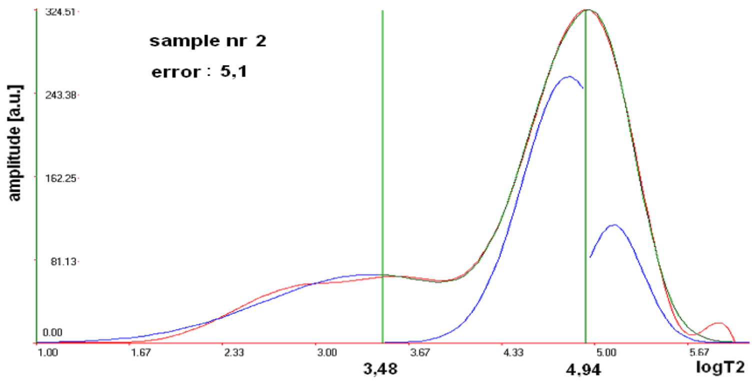

Figure. 2a.

3-modal Gaussian distribution fitting using standard T2 cut-offs for carbonates: 3ms and 92 ms, sample 2, limestone

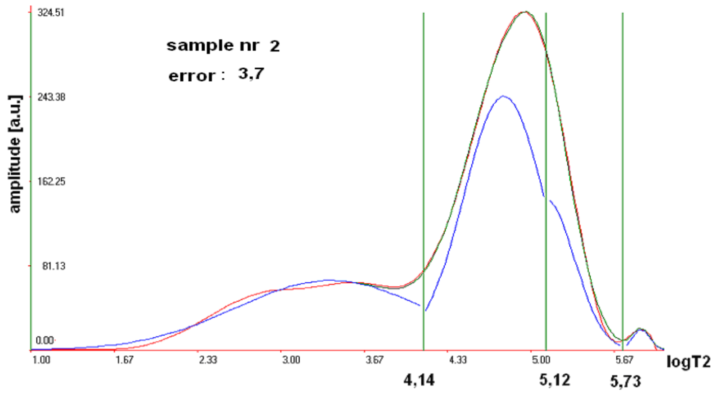

Figure. 2b.

4-modal Gaussian distribution fitting using individual T2 cut-offs: 14ms, 132ms and 537ms, sample 2, limestone

Conclusions: A new method to compute T2 cut-offs from NMR measurements was proposed. Program '*Distribution*' was developed for dividing rocks with respect to the type of pore space, on the basis individual T2 cut-offs. Standard cut-offs value often are different then real value for specific rock type. In special cases errors are about 100%. This improved method of processing NMR data enhanced division of porosity into parts occupied by free water, capillary water and bound water.

References

[1] Coates, G.R., Xiao, L., & Prammer, M.G., 1999. NMR Logging Principles and Applications. Halliburton Energy Services, Houston

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[3] Puskarczyk E., 2012, New Method of Nuclear Magnetic Resonance (NMR) Results Interpretation and T_2 cut-offs Calculation Using '*Distribution*' Program, Proceedings of the Geopetrol2012 Conference, Zakopane, 2012 (in Polish, abstract in English)