Automated Determination of Formation Porosity from Drill Cuttings using Nuclear Magnetic Resonance

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Introduction

Drill cuttings are seen as economic, abundant and early samples of drilled formations. While not usually performed, porosity measurement of cuttings could be done for petrophysical evaluation of reservoirs. Its usability in Advanced Mud Logging (AML) implies a fast procedure that have to be included into the global mud logging sampling program workflow. In the case of cuttings porosity determination, two challenges must be met a) a precise measurement of a low mass of fluid b) fluid must be only present in porous space.

The first challenge can be raised by modern low-cost compact NMR spectrometers through the analysis of T2-relaxation distribution, which provides a sensitive and accurate value of the amount of fluid located inside of the measurement cell. To raise the second challenge, the preparation of selected cuttings involves the removal of all fluids located outside the pieces of rock without removing fluid located inside of the cuttings. Different methods have been proposed but they are time consuming and required a highly trained operator to get constant and reliable results, in particular if cuttings are numerous and brittle.

A new procedure of porosity determination that may be performed by an operator that does not need to be specifically trained or by an automated system, is presented.

Cuttings porosity from NMR measurement

18 MHz Benchtop NMR spectrometer (~ 50 k€)
Sample capacity 1 in³ => 2 g of cuttings (total mass **Mt**)
Less than 180s => mass of fluid **Mw** = $I_o/I_o^{standard}\ M^{standard}$

If cuttings of known mineralogy (**ρs**) are fully saturated by a known fluid (**ρw**)

Porosity n (%) = Mw/[Mw +(Mt-Mw) ρw/ρs] . 100

Accuracy of Porosity value from NMR (limestone ρs = 2.71 g/cm³)

10 < **n** < 25 % => 80 mg < **Mw** < 220 mg

Mw error < 5 mg => porosity error < 0.5 pt

Mw accuracy from NMR is 2 mg < 5 mg

NMR porosity of cuttings is possible.

But fluid must only be present into pores and delicate and complex preparation procedures must be used to remove external fluid present in the form of:
a) fluid films coating the surface roughness;
b) capillary bridges between cuttings.

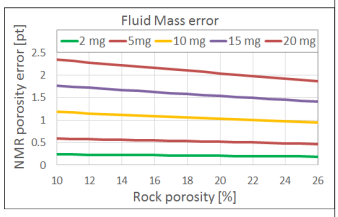


Fig 1: NMR porosity error as a function of the fluid mass error

How to quantify external fluid?

NRM fluid mass is defined by the sum of T_2 distribution coefficients, and conventional cutoffs characterize the repartition of fluid inside of the porous space of cuttings (Fig 2.)

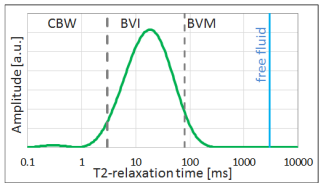


Fig 2: T_2 distribution of a set of cuttings without external fluid

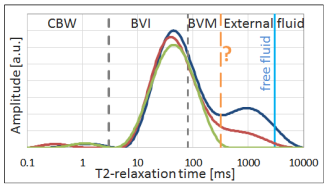


Fig 3: T_2 distribution of sets of cuttings with decreasing amounts of external fluid

If cuttings are roughly drained or wiped, the right-end of T_2 distribution exhibits the influence of remaining external fluid, but a cutoff value separting BVM to external fluid cannot be defined (Fig 3).

A corrected T2 distribution is defined:
a) by selecting the right tail of the curve (Fig 4a);
b) by calculating a peak representing the contribution of external fluid (adjustement of the selected curve + controlled symmetry) (Fig4b);
c) by substracting this peak to the initial distribution (Fig 4c).

This corrected T2 distribution defines corrected values of fluid mass, **Mw'** and NMR porosity, **n'**.

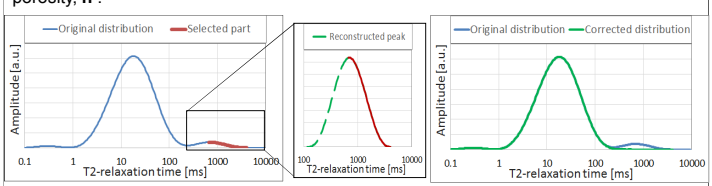


Fig 4: a) Initial T_2 distribution b) Calculated external fluid peak c) T_2 corrected distribution

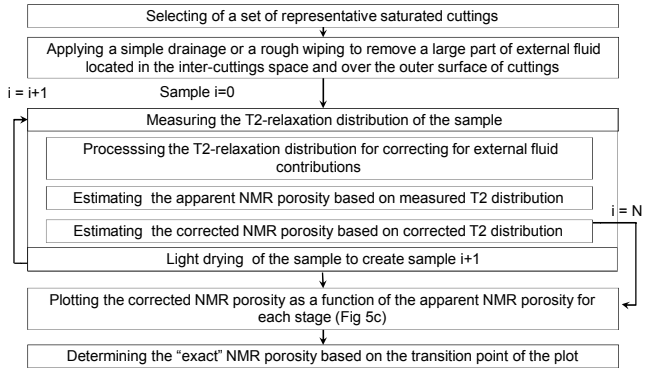
If cuttings are oversaturated, the corrected NMR porosity is lower than the NMR porosity, but if cuttings are undersaturated, both values are equal.

Starting from a set of oversaturated cuttings, successive NMR measurements during a step by step drying until cuttings are lightly undersaturated allow to identify a transition between these two conditions.

The NMR porosity calculated with the fluid mass of the transition point is an "exact" value of cuttings porosity which is not dependent on the preparation of cuttings.

New procedure of porosity determination

An iterative procedure starting from a initial set of oversaturated cuttings is proposed



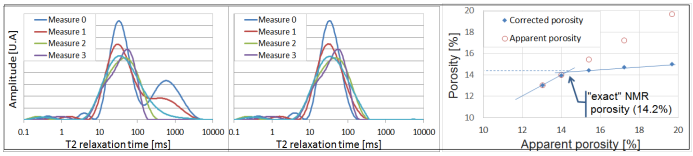


Fig 5: a) Initial T_2 distributions b) T_2 corrected distributions c) NMR porosity crossplot

Validation

7 large blocks of different limestones with uniform porosity ranging from 10 to 22 % have been selected. Cuttings have been produced under in situ conditions by using the large scale drilling facilities of Armines located in Pau (Fig 6).

NRM porosity measurements of lithic cuttings were carried out with the automated procedure. "Exact" NMR porosity values are compared to reference porosity values (Triple weighing). Deviations are less than 1.5 pt over the entire range of porosity and facies (Fig 7).

Fig 6: Armines drilling facilities and a large block

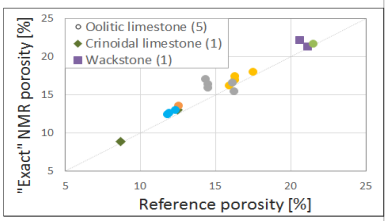


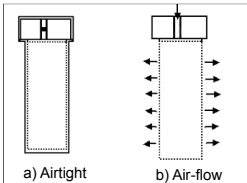
Fig 7: Comparison of NMR and reference porosities

Conclusion

A new procedure that includes successive NMR tests using a unique sample of cuttings has been validated. It provides an "exact" NMR porosity which is not dependent on the initial preparation of the tested sample that may be done by an untrained operator.

Once the initial sample is prepared and weighed, the entire procedure can be automated by using a special cell (Fig 8) handled by an automated manipulator arm.

This cell has 2 configurations:
a) Airtight configuration during NRM tests;
b) Air-flow configuration during the drying stages.



a) Airtight configuration b) Air-flow configuration

Fig 8: Special cell for an automated measurement

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