geoconvention
Calgary • Canada • May 13-17 2019

Overview Of NMR Techniques For Core Analysis

M. J. Dick, D. Veselinovic and D. Green
Green Imaging Technologies

Summary

Nuclear magnetic resonance (NMR) can be used to investigate many petyrophysical properties of cores including the types of fluid present,the size of the pores, wettability, sweep efficiencies, gas isotherms, and capillary pressure. As a result, NMR has become powerful tool in the core analysis laboratory. Originally, it was found that the NMR transverse relaxation time (T_2) directly related to the size of the pores. From this interpretation, techniques were developed to determine bound versus mobile fluid and permeability. Fluid self diffusion and/or longitutal relaxation times can also be measured in conjuction with T_2 to determine and quantify the types of fluids present in cores. Imaging techniques examine the fluid saturations directly and EOR floods can be monitored to detemine many properties including sqeep efficiency. Measurements of pressurized methane can be perfomed to directly measure the gas isotherm of cores.

This talk will present an overview of the theory and technology behind NMR in the rock core lab and the audience should receive a better understanding how NMR can help maximize the value of their core.

Theory / Method / Workflow

NMR measures the quantity of hydrogen in a sample. It is this ability to measure only signal from hydrogen containing molecules that makes NMR a powerful technique for core analysis [1]. For a core sample saturated with oil or water there will only be signal from the oil or water in the pores. The majority of the time, there will be no signal from the rock matrix itself. In addition, the hydrogen in the sample can be localized, meaning one, two or three dimensional images of the sample can be produced allowing the location of the oil or water in the samples to be visualized.

More important than NMR's ability to visualize the hydrogen content in a sample is that NMR signal lifetimes are dependant on the environment within the core that the hydrogen is occupying. For example, the transverse relaxation time (T_2) is related to the surface to volume ratio of a pore via the following equation.

$$\frac{1}{T_2} = \frac{1}{T_{2-Bulk}} + \rho\frac{S}{V}$$

Where S/V is the surface to volume ratio of the pore, ρ is the relaxivity parameter and T_2-bulk is the T_2 relaxation time of the fluid. The surface, S, to volume, V, ratio is the pore size and if the bulk term is ignored, is directly related to the T_2 through the relaxivity parameter, ρ. Therefore, a plot of volume (retrieved from NMR signal) vs T_2 is the pore size distribution (Figure 1). The T_2 based pore size distribution offers additional information to porosity i.e. what size pores the oil is in and hence how hard it will be to retrieve. This fluid/pore dependency can be exploited to determine wettability.

By adding external forces/changes to the core, NMR measurements before and after can lead to determination of advanced petrophysical properties such as capillary pressure and relative permeability.

Results, Observations, Conclusions

Both the ability of NMR to visualize hydrogen content in samples and the connectivity of NMR relaxation times to the environment within the pores are exploited to unlock a wealth of information about the properties

of cores. Visulazing the hydrogen content is employed to generate saturation profiles of cores and monitor sweep efficiencies in real time in enhanced oil recovery experiments [2]. Also coupling centrifugation with NMR saturation profiles, capilary pressure curves can be generated [3]. These NMR based capillary pressure curves are more accurate and can be generated more quickly then conventional methods. The NMR capillary pressure measurement has reduced the experiment time from weeks down to hours.

The pore size distribution generated by NMR signal lifetimes are employed in a whole series of experiments [4]. They are used to distinguish bound from free fluid and are employed calibrate down hole NMR measurements. In addition, it is known that NMR relaxation times vary as a function of wettability changes in rock core plug samples [5,6]. This information was used to develop an NMR wettability index (NWI) based on pore size distributions [7,8]. The NWI method is capable of measuring changes in wettability as a function of oil/water saturations unlike traditional methods which are based on measurements at S_{wi} and S_{or} only.

Novel/Additive Information

Work continues to develop new procedures and techniques to further exploit the capabilities of NMR to probe the characteristics of core samples. Recently a procedure has been developed to derive the gas isotherm of unconventional core samples via NMR [9]. This new method is superior to traditional techniques as it is non destructive to the core samples and provides pore size distributions as a function of pore pressure in addition to the isotherm itself.

Another avenue currently being exploited in NMR core analysis is coupling of measurement of transverse relaxaition time (T_2) with measurement of longitudinal relaxation time (T_1) or diffusion via the implementation of complex NMR pulse sequences [10]. These new sequences result in T_1-T_2 or T_2-Diffusion correlation maps [11]. The second dimension provided by these two-dimensional maps (as compared to one dimenisonal T_2-pore size distributions) aids in the uncoupling of signals from the various fluids in core samples. In particular, these maps have been successfully employed to distinguish oil, water and bitumen in shale samples.

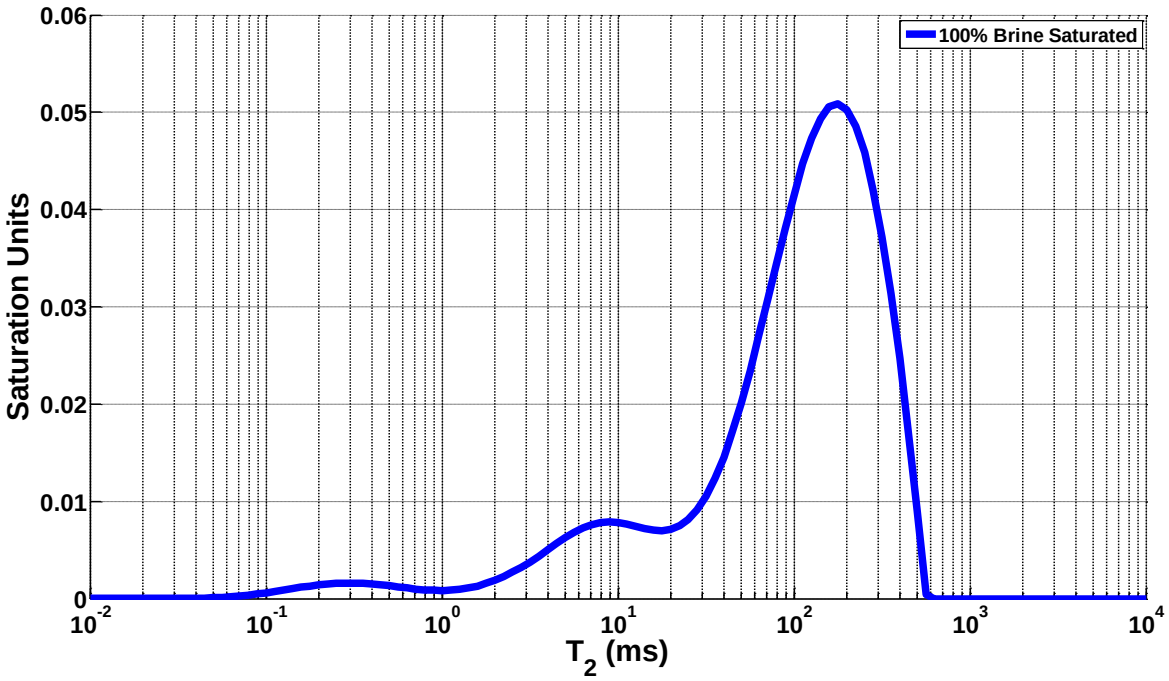

Figure 1: Typical T_2-pore size distribution for a 100% brine saturated sandstone core sample.

References

1. Coates,G.R., Xiao, L. and Prammer, M.G., *NMR Logging. Principles & Applications*, Halliburton Energy Services, Houston, 1999.
2. Romanenko, K. and Balcom, B.J.,"An Assessment of Non-Wetting Phase Relative Permeability in Water-Wet Sandstones Based On Quantitative MRI Of Capillary End Effects", Journal of Petroleum Science and Engineering (2013), 110, 225-231.
3. Green, D., Dick, J., Gardner, J., Balcom, B. and Zhou, B., "Comparison Study of Capillary Pressure Curves Obtained Using Traditional Centrifuge and Magnetic Resonance Imaging Techniques", Society of Core Analysts, Calgary, Alberta, Canada 9-14 September 2007**.**
4. Rylander, E., Singer, P. M., Jiang, T., Lewis, R., McLin, R. and Sinclair, S. SPE-164554 (2013).
5. Fleury, M. and Deflandre, F., "Quantitative evaluation of porous media wettability using NMR relaxometry", Magnetic Resonance Imaging (2003), **21**, 385-387.
6. Howard, J.J., "Quantitative estimates of porous media wettability from proton NMR measurements", Magnetic Resonance Imaging (1998), **16**, 529-533.
7. Looyestijn, W.J. and Hofman, J.P., "Wettability Index Determination by Nuclear Magnetic Resonance", SPE 93624, presented at the MEOS, Bahrain, March 2005. Published in SPEREE April 2006, pp 146 – 153.
8. Looyestijn, W., Zhang, X., and Hebing, A., "How can NMR assess the wettability of a chalk reservori", Society of Core Analysts, Vienna, Austria, 27 August-1 September 2017.
9. Dick, M. J., Muir, C., Veselinovic, D. and Green, D. "Measuring Methane Adsorption in Shales Using NMR", Society of Core Analysts, Vienna, Austria, 27 August-1 September 2017.
10. Veselinovic, D., Dick, M. J. and Green, D. "NMR at Different Temperatures to Evaluate Shales". Unconventional Resources Technology Conference, Austin, Texas, 24-26 July 2017.