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Understanding Relationships Between NMR and Pore Size Distributions in Porous Media

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Summary

Conventional wisdom for NMR interpretations of water-saturated porous media is that the NMR spectra are analogous to the pore size distribution of the system. This is the basis for understanding porous media as containing large vs. small pores, and is used as a justification for NMR-based permeability correlations. However, there are cases whereby issues of poor connectivity between pores can skew the NMR T_2 distribution such that it may no longer be representative of the pore sizes present in the core. This in turn can lead to errors in characterization of a given porous medium. This work investigates this potential problem by constructing a digital rock model and performing pore-level simulations in order to generate the corresponding NMR pore size distribution for this system. The same physical pore size distribution is maintained, but the connectivity is reduced between the different pores, and the corresponding shifts in the NMR distribution are observed.

Introduction

NMR spectra of water-saturated cores are commonly accepted as being analogous to pore size distributions (Kleinberg and Vinegar, 1996; Coates *et al*., 1999). Conventional wisdom says that NMR spectra can yield the fraction of large vs. small pores in a core sample, and this can have potential implications for understanding flow properties such as permeability, or the perceived ability to displace hydrocarbons in different pore systems. In many cases NMR spectra are compared against mercury injection pore size distributions, and the shape of the spectra are generally anticipated as being qualitatively similar. However, in some cases this does not happen. When NMR spectra do not look qualitatively similar to other methods of measurement of pore size distribution, the question arises as to why this happens.

Method

Figures 1 and 2 present samples of core with NMR T_2 spectra correlated against MICP data. In these samples, the procedure that was followed was to saturate cores with brine and measure NMR spectra. These spectra are taken to be analogous to the pore body size distribution. Subsequently cores were cleaned and dried, and then mercury was injected at varying fixed pressures. At each recorded pressure the volume of mercury was determined. Effective pore throat radius is calculated from the Hg injection pressure, and the injected Hg volume gives the corresponding volume of pores that can be accessed by that level of capillary pressure (or less). In this manner, Hg injection is really giving a pore throat size distribution, but at each limiting pore throat size, the actual volume of Hg that enters the core is the volume of all associated larger pore bodies and pore throats. It is generally thought that, in the absence of diagentic processes like what is present in some carbonate reservoirs, there will be a relationship between pore bodies and pore throats. Thus, by tuning the effective NMR surface

relaxivity, the NMR spectra can be overlaid against MICP output data. In Figure 1 this seems to have worked well on a qualitative basis: here the NMR and MICP data both show a broad range of pores and a bi-modal/tri-modal pore size distribution. In contrast, in Figure 2 the measured MICP pore size distribution shows what appears to be a bi-modal pore size distribution, with significant overlap between large and smaller pore size peaks. The NMR shows three distinct peaks, and no longer seems to correlate with the "true" MICP-based pore size distribution.

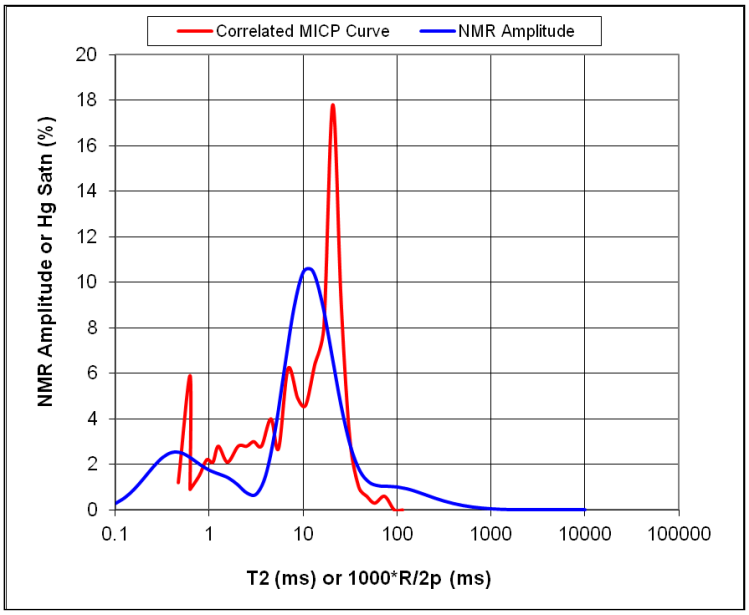

Figure 1: Example of NMR and MICP with good qualitative match between the two measurements

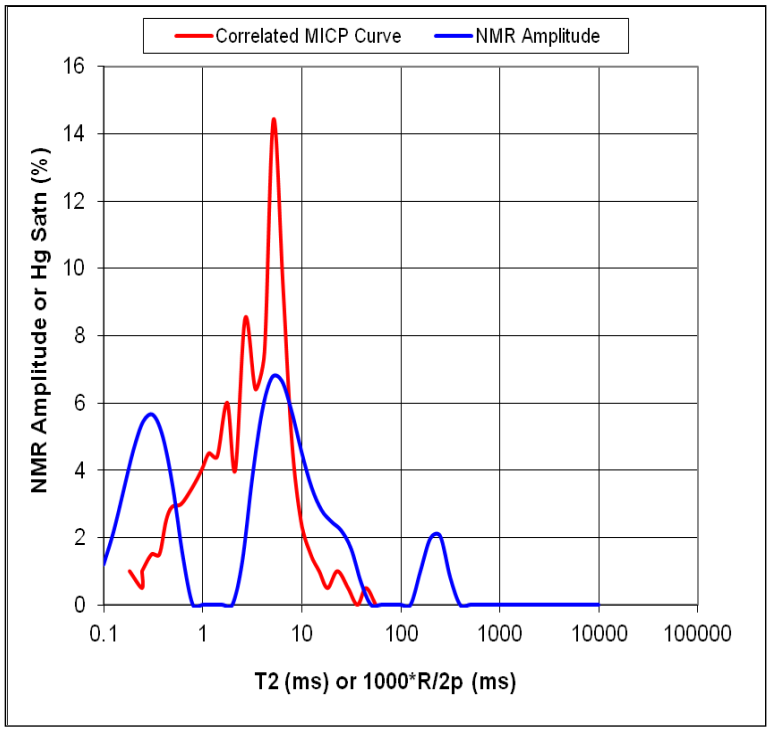

Figure 2: Example of NMR and MICP with poor qualitative match between the two measurements

The conditions need to be better understood wherein NMR may or may not be related to the true pore size distribution of the system. This problem was tackled by looking at a synthetic pore size distribution using a pore level numerical simulator.

We consider a 3D porous media pattern, and perform the NMR study using COMSOL multi-physics numerical simulation software. The pore sizes and shapes vary significantly and are of order hundreds of microns. The pores are interconnected, and thus on average, molecules will sample the entire range of pore sizes before being relaxed. In this case, the relaxation will have a decay rate

$$\left(\frac{1}{T_2}\right)_S = \rho\left(\frac{S}{V}\right)_0$$

where ρ is the surface relaxivity strength and the surface to volume ratio $\left(\frac{S}{V}\right)_0$ is for the entire space and not just a single pore. We include clay in the porous media with a higher surface relaxivity than the rocks. One then expects the NMR spectrum to be shifted to the left as the excited protons are relaxed more quickly due to the surface relaxation of the clay samples. However, in a configuration where the clay is constricting the throats such that no diffusion into the smaller pores can occur, the pore space becomes isolated. Hence, the dominating relaxation mechanism will be due to the bulk relaxation, and diffusion will be limited to that pore space. This will in turn cause the NMR spectrum to be shifted further to the right.

This model was used as a theoretical porous medium, for which the true pore size distribution is known. The corresponding NMR T_2 distribution could be calculated for such a system, and then changes in the T_2 distribution can be observed by varying parameters such as the connectivity between pores, and the surface relaxivity of the rock material. In this manner, the physical pore size distribution in the digital model is not changing, but by varying parameters in the model, it is possible to see the corresponding effect on the NMR T_2 distribution that is output for the system.

Examples

The digital rock model approach is demonstrated in the images shown in Figures 3 and 4. Figure 3 shows an assumed pore size distribution (two-dimensional image) with good connection between different pore sizes. In contrast, Figure 4 shows exactly the same 2D pore size distribution, but now some of the pore connections are reduced by solid fines that are blocking the pore throats. In this example, even though the physical pore sizes have not changed in the model, the NMR spectra will look quite different in the case of well connected vs. poorly connected pores.

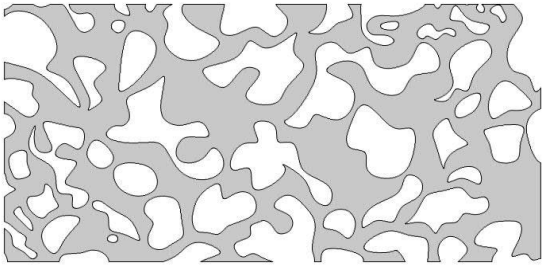

Figure 3: 2D digital rock model image with well connected pore

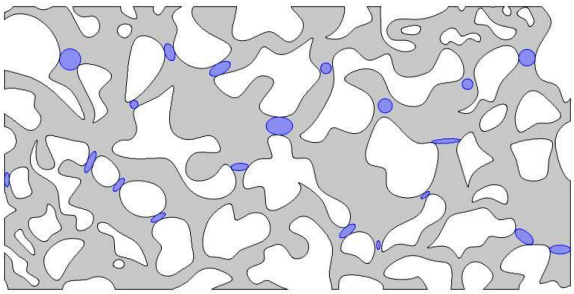

Figure 4: 2D digital rock model image with poorly connected pores

The 3D digital rock model, constructed using more regular solid grain shapes, allows for an understanding how sensitive are the NMR spectra to pore connections when present in 3D space, i.e. where there are many more pore connection pathways than in the more simple 2D system.

Acknowledgements

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