Rapid non-destructive Capillary Pressure Measurements with NMR

Application Note 2

Capillary pressure is a critical parameter for the oil exploration and production industry, and is a common measurement performed in core analysis laboratories. However, traditional techniques such as porous plate, centrifugation and mercury injection are laborious, time consuming and expensive.

The method described here was first reported by Dr. Derrick Green of Green Imaging Technologies at a meeting of the Society of Core Analysts in 2007. Called GIT-CAP™, it centrifuges core plug samples and then directly measures the water saturation distribution using a one-dimensional NMR profile (a simplified version of Magnetic Resonance Imaging, or MRI). This technique is as accurate as porous plate and is 5 times faster than traditional centrifuge capillary pressure measurements.

Method

The patented GIT-CAP capillary pressure measurement technique uses capillary pressure theory combined with NMR-determined saturation profiles, allowing for the accurate development of capillary pressure curves. With this technique, the core plug is first fully saturated with brine, and is then centrifuged to create a distribution of fluid in the plug which is in turn dependent on capillary pressure. The fluid distribution is quantified using NMR. The capillary pressure at each position along the plug at hydrodynamic equilibrium is derived from equation (1) and the saturation at the corresponding positions is measured using NMR (illustrated in Figure 1).

[1] $$P_c(r) = \frac{1}{2}\Delta\rho\omega^2(r_2^2 - r^2)$$

Where Pc(r) is the capillary pressure at the given radial position, $\Delta\rho$ is the density difference of the two fluids, ω is the rotational speed and r_2 is the distance to the outlet face of the plug. This equation assumes that the outlet boundary condition of 100% water saturation (or zero capillary pressure) is maintained. This means in any centrifuged plug, there will be a distribution of saturations from 100% at the outlet to water saturation at the inlet (governed by the rotational speed).

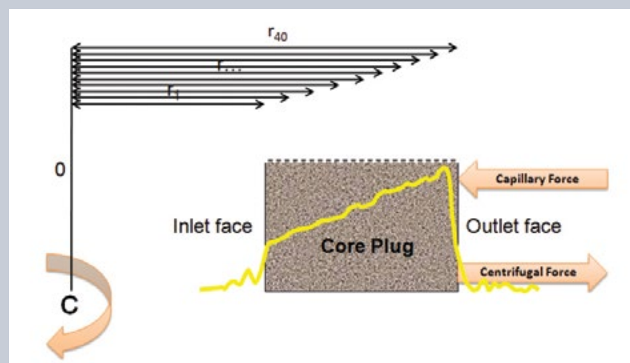

Figure 1: *GIT-CAP capillary pressure technique measuring 30 - 40 data points*

Saturation profiles acquired after centrifugation at different speeds can be plotted on the same curve expanding the range and resolution of the capillary pressure curve. This technique was proven to work on a wide range of samples (Reference 1). Accurate saturation profiles are ensured by using advanced SPRITE-based MRI techniques (Reference 2).

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Results

Typical results are shown in the following figures for two sandstone samples. The associated saturation profiles are included to illustrate the amount of fluid movement within the samples at each centrifuge speed.

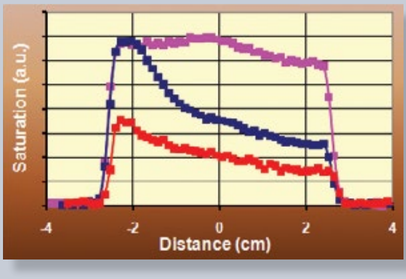

Figure 2a: *Saturation profiles for Figure 2b*

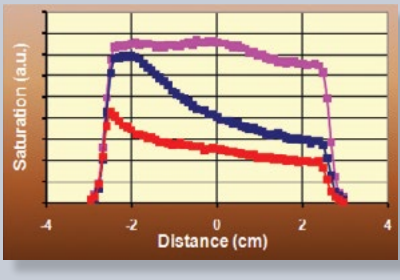

Figure 3a: *Saturation profiles for Figure 3b*

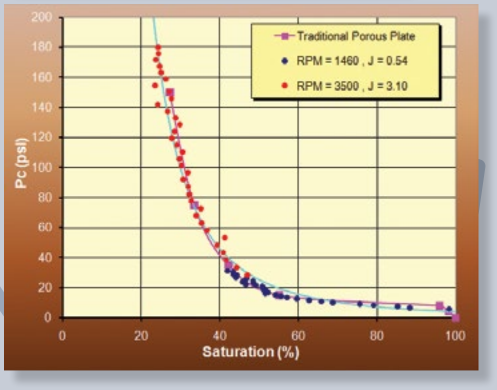

Figure 2b: *GIT-CAP capillary pressure curve for sandstone sample with a permeability of 5.74% and porosity of 20.4 mD*

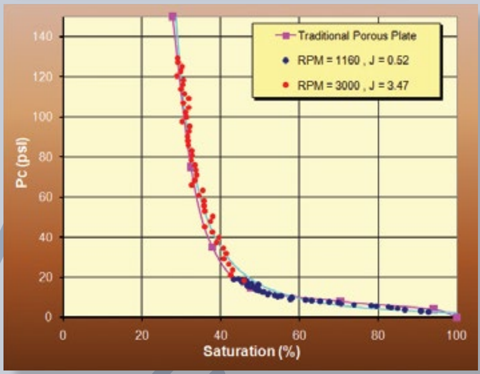

Figure 3b: *GIT-CAP capillary pressure curve for sandstone sample with a permeability of 13.7% and porosity of 9.7 mD*

As can be seen in these figures, this technique only requires two different centrifuge speeds to determine the full capillary pressure curve. The obvious advantage is that the result is obtained in a fraction of the time required for other traditional measurement techniques but it is also an accurate, direct measurement. The following table compares the GIT-CAP measurement technique to the traditional capillary pressure measurement methods:

	GIT-CAP Advantages
Mercury Injection	• Uses representative fluids • Non-destructive • Direct measurement • Simpler sample handling procedures
Traditional Centrifuge	• Speed (GIT-CAP takes days, centrifuge takes weeks) • Accuracy/more data (GIT-CAP provides 30-40 data points per centrifuge speed) • Simpler centrifuge set-up (no costly upgrades required)
Porous Plate	• Speed (GIT-CAP takes days, porous plate takes weeks or months) • More data points

With the inherent time and accuracy advantage, the GIT-CAP NMR measurement can help a laboratory increase their sample throughput by at least three times per centrifuge. The following table illustrates how to maximise sample throughput using this measurement technique:

	1 Centrifuge		2 Centrifuges	
	Traditional	**GIT-CAP**	**Traditional**	**GIT-CAP**
Samples per centrifuge	4	4	4	4
Test duration in days (including sample preparation)	10	3	10	3
Days per year	250	250	250	250
Pc Tests/year	**100**	**330**	**200**	**660**

Hardware

The advantages of the GIT-CAP measurement are bolstered by the **GeoSpec** hardware, which has substantially decreased acquisition times, as well as an increased signal to noise ratio. Decreased acquisition times make the GIT-CAP measurement even faster while the increased signal to noise ratio and short echo times ensure the data collected is more accurate. Measurements are controlled by the GIT-CAP software and can be made easily by core laboratory technicians without in-depth knowledge of NMR techniques.

Conclusion

Capillary pressure measurements using the GIT-CAP method are substantially faster than those made by traditional techniques, particularly for low permeability samples with longer equilibrium times. They also provide significantly more data points, allowing more accurate prediction of additional parameters such as pore throat distributions, wettability, and relative permeability.

References

Reference 1: *Comparison study of capillary pressure curves obtained using traditional centrifuge and magnetic resonance imaging techniques.* D.P. Green, J.R. Dick, J. Gardner, B. J. Balcom, B. Zhou. International Symposium of the Society of Core Analysts, Calgary, Alberta, Canada, (September, 2007)

Reference 2: *Spatially resolved measurement of rock core porosity.* F. Marica, Q. Chen, A. Hamilton, C. Hall, T. Al, B.J. Balcom. Journal of Magnetic Resonance 178, 136 - 141. (2006)

Additional references are provided at **www.greenimaging.com/publications**

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GeoSpec – The new approach to core analysis using NMR

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and giving fast measurement of:

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- Pore Size Distribution
- Bulk Volume Irreducible (BVI)
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- Clay Bound Water (CBW)
- Effective Porosity
- Permeability
- Capillary Pressure
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- Oil/Water Content
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- Water/Bitumen Content

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