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The Use of Advanced Nuclear Magnetic Resonance Logging for Fluid Characterization in Fresh Water Reservoirs – A Case Study of Assam-Arakan Basin, India

Abstract

Evaluating Low Contrast Resistivity reservoirs can sometimes have challenging fluid interpretation issues because of the masking of hydrocarbon response on resistivity logs. It is not uncommon to miss-out entirely on potentially producible hydrocarbon zones because of a failure to properly evaluate these Low Contrast Resistivity reservoirs. Fluid sampling may provide information on hydrocarbon types but there still remains the difficulty of establishing the interval limits of the hydrocarbon zones. It becomes very difficult to accurately identify and quantify reservoirs fluid in these kinds of reservoirs using conventional logging approach. Therefore, there is a need of advanced techniques to accurately identify & quantify these kinds of reservoirs. This paper presents an advanced multi-dimensional nuclear magnetic logging approach to counter problems associated with these kinds of reservoirs. Two candidate wells have been selected for current study where Magnetic Resonance Fluid (MRF) station readings have been acquired. The potential zones have been identified and evaluated based on this technique. From our field test results, it is concluded that 2D NMR techniques greatly increase the accuracy of fluid typing and saturation determination in oil field of Assam-Arakan Basin, India.

Introduction

One-dimensional nuclear magnetic resonance (1D NMR) logging technology has some significant limitations in fluid typing and characterizing low resistivity and low contrast reservoirs. However, not only can two-dimensional nuclear magnetic resonance (2D NMR) provide some accurate porosity parameters, but it can also identify and quantify fluids more accurately than 1D NMR. Recent advances in 2D NMR technologies have extended the NMR logging applications to perform *in-situ* fluid typing, oil saturation, and oil viscosity determination (Freedman, R., Heaton, N., and Flaum, M., 2002). This paper presents a variety of field applications that illustrate recent advances in NMR logging fluid characterization methods. The main concepts of NMR logging and the principles underlying NMR diffusion measurements, which form the basis for all standalone NMR fluid characterization methods, are briefly reviewed. Fluid characterization methods are presented to demonstrate the separation of oil and water signals, saturation measurements and oil-viscosity determination.

The Magnetic Resonance Fluid Characterization (MRF) method has been used to characterize fluid types and saturation measurements. The application of 2D NMR maps of relaxation times and molecular-diffusion rates to identify fluids and determine their properties in complex multi-fluid environments is illustrated with field examples from Geleki field, Assam-Arakan Basin. The problem of saturation measurements in low contrast resistivity or fresh water reservoirs has also been addressed. We have recently deployed such 2D NMR technology to various oil fields. 2D NMR logging was performed in real open-hole wells by CMR stationary logging. Using a set of CPMG echo train data with different echo spacing and wait time acquired by commercially available NMR logging tools and a global inversion algorithm for relaxation-diffusion (GIRD), we were able to obtain a relaxation-diffusion 2D NMR map as a function of depth (Cao Minh, C., Heaton, N., Ramamurthy, R., et al., 2003). This is a map which represents the hydrogen population as a function of both T2 relaxation time and diffusion coefficient.

Two candidate wells have been selected for current study where MRF station reading has been acquired. From our field test results, it is concluded that 2D NMR techniques greatly increase the accuracy of fluid typing and saturation determination in fresh water reservoirs in oil fields in Assam-Arakan Basin, India. The T2-diffusion correlation information can be used to determine pore size distribution, perform fluid saturation typing, and estimate in-situ oil viscosity simultaneously. These techniques can also be applied to explore internal magnetic field gradient and characterize the droplet size distribution of emulsion, measure the gas/oil ratio and determine the properties of heavy oil.

Area of Study

The study area belongs to North Assam Shelf encompassing Geleki field. The field is located at southern fringe of North Assam shelf within a close proximity to Naga Thrust and has an aerial extent of 27Sq Km ***(Fig.1).*** The Geleki structure in North Assam Shelf is a doubly plunging NE-SW trending anticline. The major part of the Geleki represents gentle flat topography whereas southern part of the field is concealed by Naga Thrust. Geleki is one of the major oil field of North Assam shelf discovered in 1968. In this field, the main HC producing formations are the Tipam (Miocene) , Barail (Oligocene) and Kopili (Eocene) ***(Fig. 2)***; they contain all together 35 sand layers. The Tipam formation is subdivided into six layers , i.e., TS-1 to TS-6 (from top to bottom). TS-2 is one of the most prolific reservoirs in Geleki. In certain of the producing formations, increase in resistivity in front of hydrocarbon bearing layers is much smaller than expected.

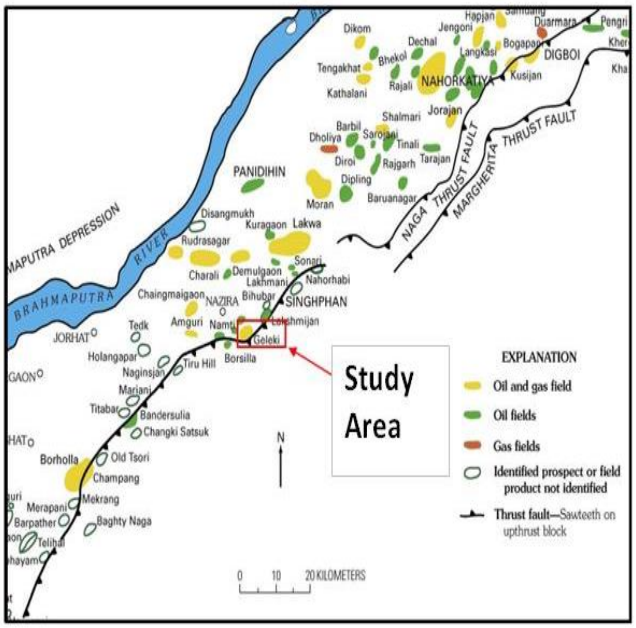


Fig: 1 Location Map of Study Area

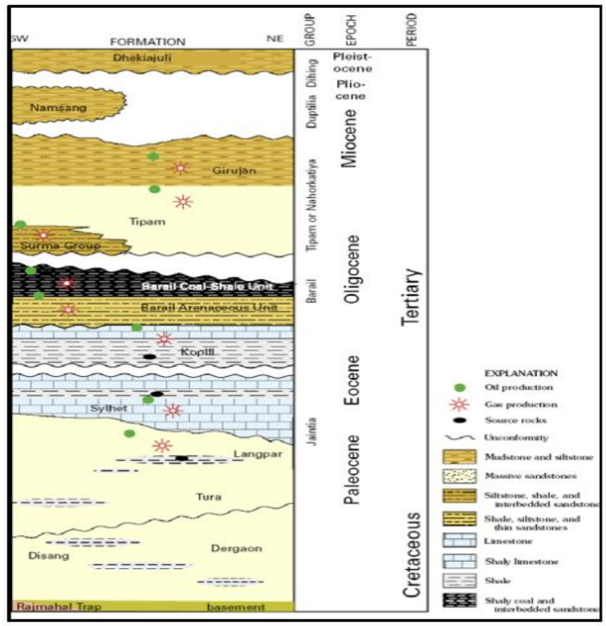


Fig: 2 Generalized Stratigraphy of the Study Area

Formation Evaluation Challenges

The Geleki field has very complex lithology, as inferred from petrography and XR-Diffraction studies (Kumar *et al.,* SPE 64521). It contains many minerals (quartz, feldspar, silt, high amounts of micas (Muscovite, Biotite), Authigenic Clays: montmorillonite, kaolinite, and Illite. Micas complicate log analysis as most lithology indicators reflect it as high-density shale, resulting in pessimistic reservoir evaluation and under estimation of true porosity and permeability. Also, the poor contrast in resistivity between HC zones and water zones make it difficult to characterize reservoirs fluids using basic logs. Thus, based only on conventional log analysis, it is not possible to accurately discern and quantify reservoir saturation. Therefore, there is a need of advanced log analysis to accurately define the reservoirs.

Magnetic Resonance Fluid Analysis

The T2 spectrum measured by an NMR logging tool is a composite (**Fig.3**) of the constituent components of the reservoir fluids in the pore space. If there is no T2 contrast between the fluids, it is impossible to determine the type of fluid and the quantity of each fluid based solely on T2. In the event that 1D NMR, or T2 logging, is insufficient to differentiate fluids, alternative techniques must be used to determine reservoir fluid type and quantity.

A common technique employed in other industries using NMR is two-dimensional 2D NMR imaging. With recent advances in borehole NMR technology, 2D NMR techniques now are available for reservoir fluid identification and quantification. While seemingly much more complex, 2D NMR plots are similar to conventional crossplots in that one NMR fluid property is plotted versus another NMR fluid property and patterns in the data are used to identify and quantify the reservoir fluid. The position of the various data clusters on the 2D maps (Diffusion coefficient versus T2intrinsic) is the basis for making fluid interpretation on diffusion maps (Akkurt, R., Ahmad, N.A., Behair, A.M., Abdallah M.B., Rabaa, A.S., Crary,., 2008). The basic interpretation model for the NMR diffusion maps is provided in **Fig.4**.

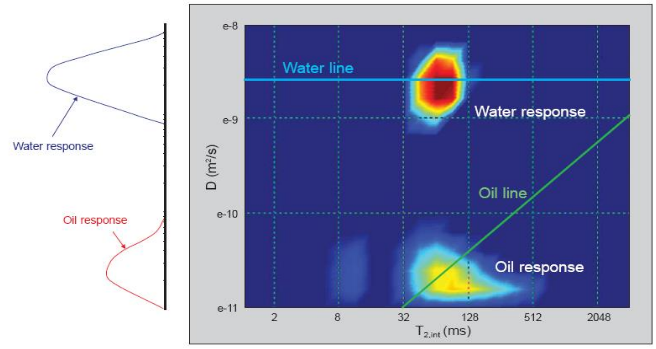


Fig .4 D vs. T2, 2D NMR image, crossplot of D spectrum and T2 spectrum

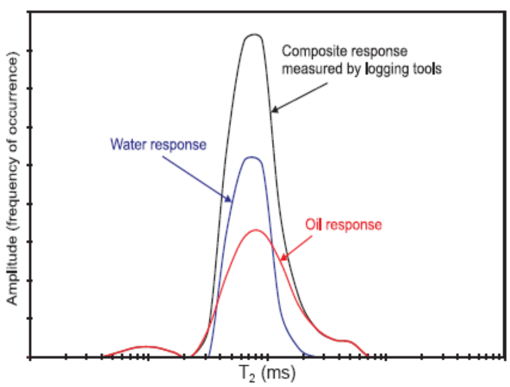


Fig .3 Moveable water and viscous oil, same T2

The MRF method has been used to characterize fluid types and saturation measurements. The MRF method exploits molecular diffusion in the field gradient generated by the tool magnet. This process leads to an additional NMR decay proportional to the square of the echo spacing and to the diffusion constant of each fluid component governed by the simple equation (Akkurt, R., Bachman, H.N., Minh, C.C., Flaum, C., LaVigne, J., Leveridge R., 2009)

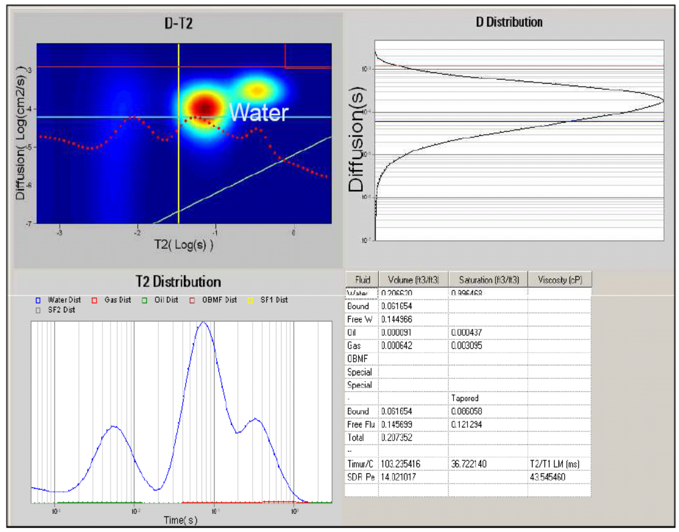
$$\frac{1}{T_{2D}} = \frac{D(\gamma G)^2 TE^2}{12}$$

where TE – Echo Spacing, D – Diffusion Coefficient, G – Tool Gradient.

Because water molecules are typically smaller and more mobile than the hydrocarbon molecules in crude oils, the water signal decays faster than the oil signal for long-echo spacings (Akkurt, R., Vinegar, H., Tutunjian, P., and G uillory, A., 1996). By inverting a specially designed suite of NMR measurements with different echo spacings, the MRF method separates brine and oil signals **(Fig. 5,6&7)** even when the T2 distributions completely overlap.

Field Examples

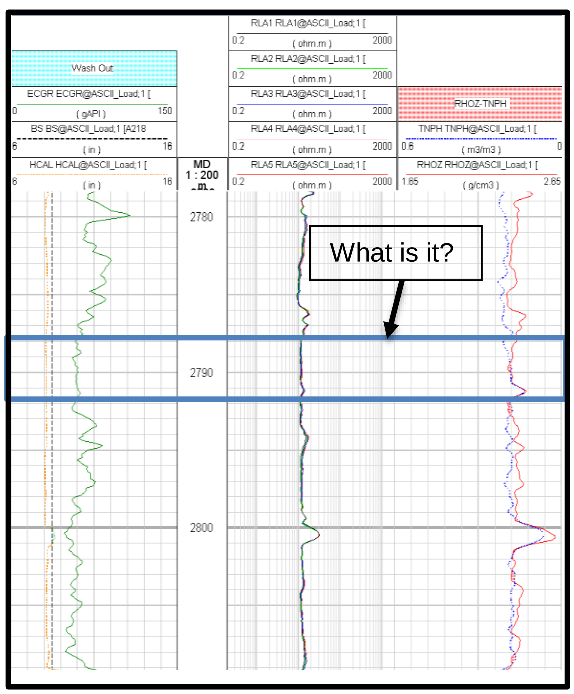
Two examples of field logs from Geleki field, Assam-Arakan Basin, India have been taken in this case study. These examples show brine and oil T2 distributions, saturations, and oil viscosities from MRF analysis of station logs acquired at different depths.



Depth: 2789m T2cutoff=33ms, Reg=16

NMR Case study Well-X1

The major challenge in Well-X1 was the fluid identification and quantification in the intervals 2787 – 2792 & 2668 – 2671m. The response of all basic logs like resistivity, density, neutron & gamma ray are almost similar for both the zones **(Fig.5 & Fig.6)**. As can be seen from the figures below that based only on conventional log analysis, it is not possible to accurately discern and quantify reservoir saturation in these intervals as the response of conventional logs is similar for both zones. Therefore, CMR MRF station logs had been acquired at depth 2789m & 2669m. Figure 5 shows the CMR-MRF analysis for the depth 2789m. The position of the various data clusters on D-T2 plot lies on the water line indicating the interval to be water bearing having porosity 20% and permeability 103mD. Figure 6 shows the CMR-MRF analysis for the depth 2669m. The position of the various data clusters on D-T2 plot lies above the water line indicating the presence of light oil having viscosity 2.29cp. The CMR-MRF resolved the enigma of low contrast in resistivity between hydrocarbon zones and fresh water zones in this well and helped in identifying and quantifying the correct fluid type. Based on this study, flushed zone oil saturation at depth 2669m is around 27%. The interval was perforated and produced oil.



CMR MRF station at 2789m, indicating water
PHI=20%, K=105mD

Fig.5 MRF analysis of the data acquired by the CMR tool@2789.Right most is the diffusion map with the colored circle defining the spread of the data. MRF station point analysis confirms the presence of water.

Depth: 2669m, T2cutoff=33ms, Reg=16

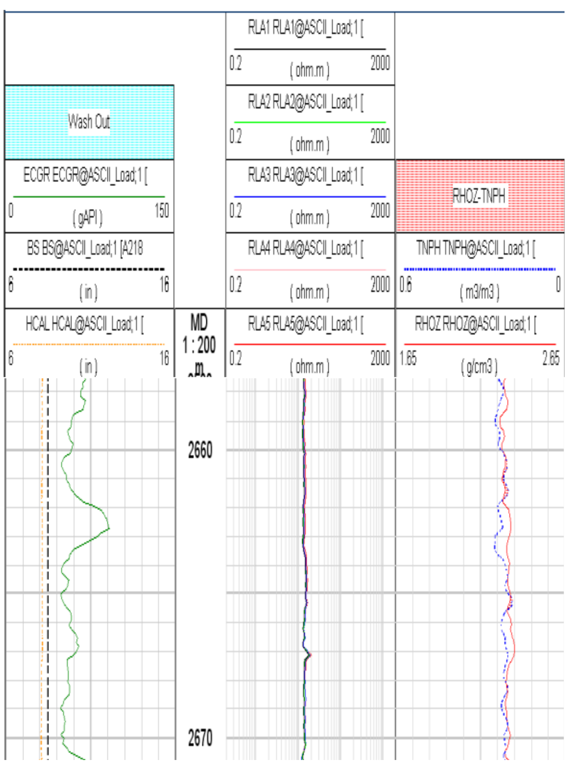
Fig.6 CMR-MRF analysis resolved the enigma of low contrast resistivity Left is the conventional log suit. Right most is the diffusion map with the colored circle defining the spread of the data.

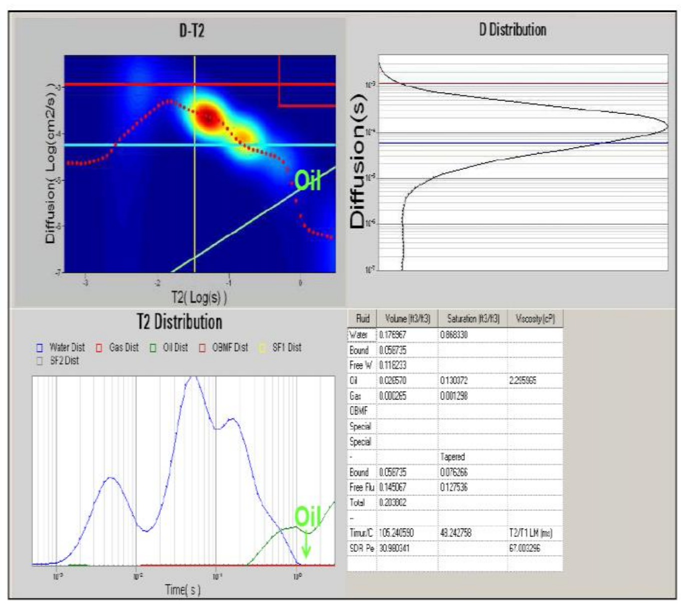
NMR Case study Well-X2

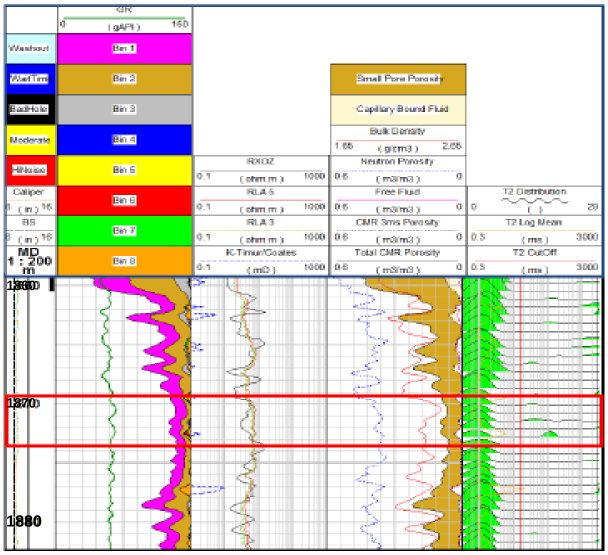
The major challenge in Well-X2 was the fluid identification and quantification for the interval 1870 – 1818 m (**Fig.7**). Based only on conventional log analysis and CMR T2 distribution, it is not possible to accurately discern and quantify reservoir saturation in this interval. However, CMR-MRF analysis helped in identifying and quantifying the correct fluid type. MRF station measurements were made at 1871 m (**Fig.7**). Based on this study, MRF analysis indicates the presence of light oil as data cluster on D-T2 map lies above the water line (**Fig.7**).

Similar Response like water zone

CMR MRF station at 2669m, indicating light oil with Sxoil=13%, Viscosity=2.29cp, PHI=20%,







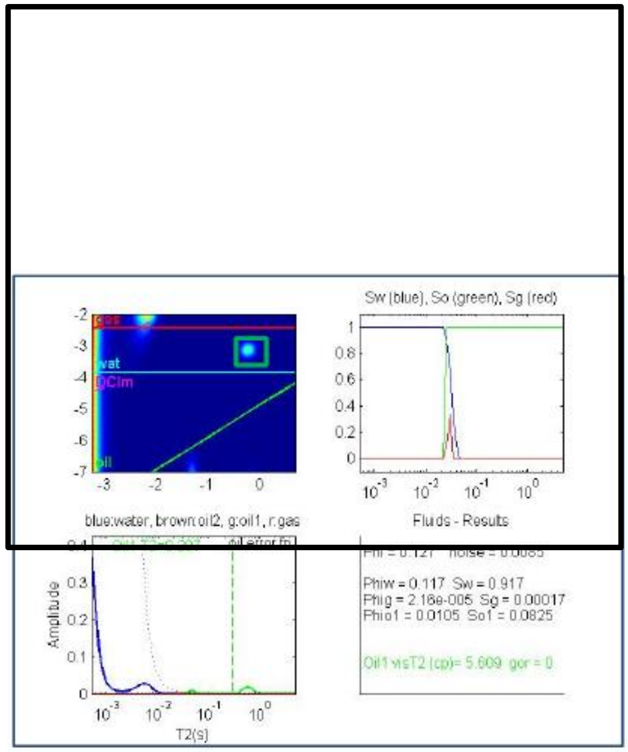


Fig.7 Left is the conventional log suit with CMR T2 distribution for Well-X2. MRF data was acquired by the CMR tool @ 1871.0 m. Right most is the diffusion map with the colored circle defining the spread of the data.

Results and Discussion

The analysis provides accurate results in fresh water or low contrast resistivity reservoirs and in reservoirs in which the brine and oil distributions completely overlap. In Well-X1, the MRF analysis solved the enigma of low contrast resistivity. MRF station measurements were made at depth 2292.5 m. The points are falling on in between water line & oil line (**Fig.6**). Based on MRF analysis, the said interval was having flushed zone oil saturation around 48%. The interval was perforated and produced oil. In Well-X2, MRF station measurements were made at depth 1871.0 m (**Fig.7**). The data points are falling above the water line on the D-T2 diffusion map, indicating the presence of light oil.

MRF technology can also provide solutions in fresh or varying salinity formation waters, where Archie resistivity analysis is difficult. Using direct hydrocarbon characterization, pay intervals can be identified even in zones with low contrast resistivity. The MRF method can over- come problems associated with Archie analysis, such as varying cementation exponent; dipping, thin or laminated beds that affect resistivity tools and unknown or varying water resistivity. This method also overcomes incorrect permeability calculations caused by hydrocarbon effects. The MRF method works in viscosities from less than 1 cp to more than 200 cp. For viscosities below this range, the DMR* Density-Magnetic Resonance method should be used because hydrocarbons that are very light (such as gas and condensate) result in porosity deficits. Above 200 cp there is a lack of diffusion sensitivity.

Conclusion

Based Upon the present studies and from our field test results, it is concluded that Two Dimensional NMR techniques greatly increase the accuracy of fluid typing and saturation determination in Geleki oil field in Assam-Arakan Basin of India. It has been found that the analysis provides accurate results even though the brine and oil T2 distributions completely overlap and in fresh water reservoirs having low contrast in resistivity between water zones and hydrocarbon zones.

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References

Akkurt, R., Ahmad, N.A., Behair, A.M., Abdallah M.B., Rabaa, A.S., Crary, S.F., Thum, S., 2008, NMR Radial Saturation Profiling For Delineating Oil-Water Contact in a High Resistivity Low-Contrast Formation Drilled with Oil-Based Mud. SPWLA paper presented at the 49th Annual Logging Symposium in Edinburgh Scotland, May 25-28.

Akkurt, R., Bachman, H.N., Minh, C.C., Flaum, C., LaVigne, J., Leveridge R., 2009, Nuclear Magnetic Resonance Comes Out Of Its Shell, Oilfield Review, Winter 2008/2009 No. 4, pp 4 –23

Allen, D., Crary, S., Freedman, B., Andreani, M., Klopf, W ., Badry, R., Flaum, C., Kenyon, B., Kleinberg, R., G ossenberg, P., Horkowitz, J., Logan, D., Singer, J., and W hite, J., 1997, How to use borehole nuclear magnetic resonance: Schlumberger Oilfield Review, vol. 9, no. 2, p. 34–57.

Akkurt, R., Vinegar, H., Tutunjian, P., and G uillory, A., 1996, NMR logging of natural gas reservoirs: The Log Analyst, vol. 37, no. 6, p. 33 – 42.

Cao Minh, C., Heaton, N., Ramamoorthy, R., Decoster, E., White, J., Junk, E., Eyvazzadeh, R., Al-Yousef, O., Fiorini, R., and McClendon, D., 2003, Planning and interpreting NMR fluid-characterization logs, SPE 84478 presented at the SPE Annual Technical Conference and Exhibition.

Freedman, R., Heaton, N., and Flaum, M., 2002, Field applications of a new nuclear magnetic resonance fluid characterization method: SPE Reservoir Evaluation & Engineering Journal, vol. 5, no. 6, p. 455–464.