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Reservoir Fluid Characterization Using Multi-Dimensional Nuclear Magnetic Resonance Logging in Low Resistivity Low Contrast Reservoirs – A Case Study in Oil Fields of Bombay High, Western Offshore - India

Abstract

Evaluating Low Resistivity Low Contrast 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 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. In many cases, hydrocarbon zones are basically assumed to be in virgin state at the time of discovery, with single fluid contacts defining the reservoir fluid distribution. 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 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 fields in western offshore of India.

Introduction

One-dimensional nuclear magnetic resonance (1D NMR) logging technology has some significant limitations in fluid typing and characterizing low resistivity low contrast (LRLC) 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 Heera field, Mumbai High. The problem of saturation measurements in low resistivity 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., Ramamoorthy, 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 oil fields in western offshore of 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

Bombay High (now Mumbai High) is an offshore oilfield located in the Arabian Sea, approximately 160km west of the Mumbai coast. Discovered in 1974, the field started production in 1976. The oil field consists of two blocks named Mumbai High North (MHN) and Mumbai High South (MHS). The blocks were divided based on shale barrier assisting in independent exploitation of reserves at the north and south fields of Mumbai High. Present study belongs to Heera Field (Fig.2) which is located 75 km South-West of Mumbai city in Arabian Sea. This field is on a basement horst (Fig.1) bounded by faults on all four sides.

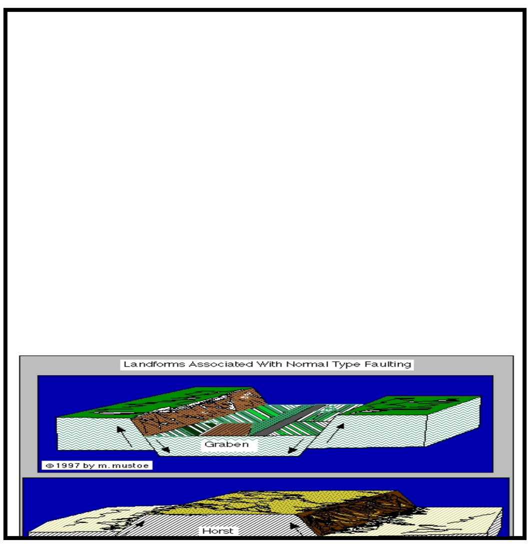


Fig. 1 Horst Structure

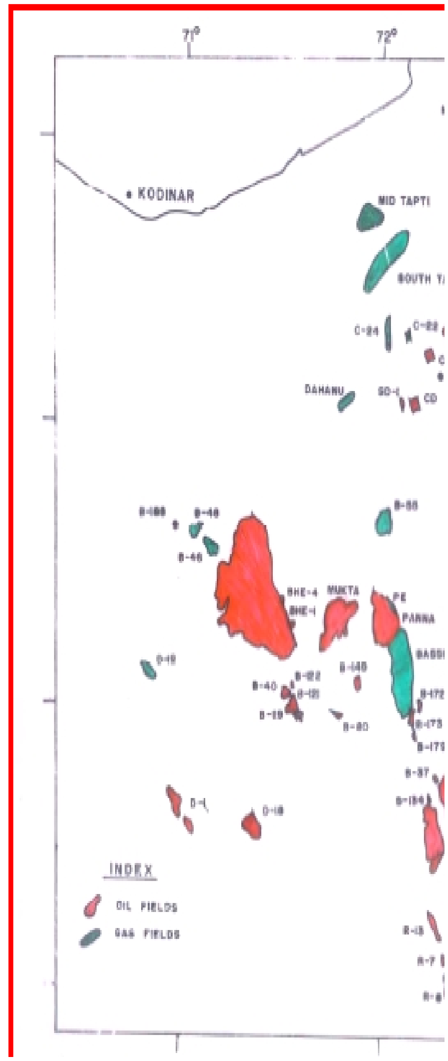


Fig.2 Geological Map Showing Cambay Basin

Magnetic Resonance Fluid Analysis

The T2 spectrum measured by an NMR logging tool is a composite (Fig.3) of the constituent components (2) 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, S.F., Thum, S., 2008). The basic interpretation model for the NMR diffusion maps is provided in Fig-4.

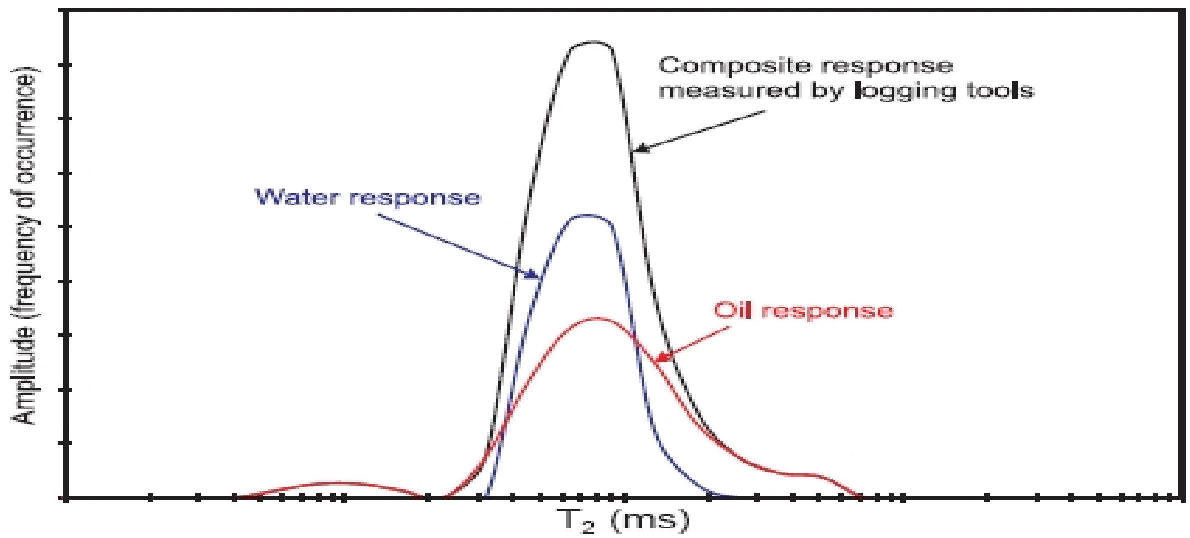


Fig .3 Moveable water and viscous oil, same T2

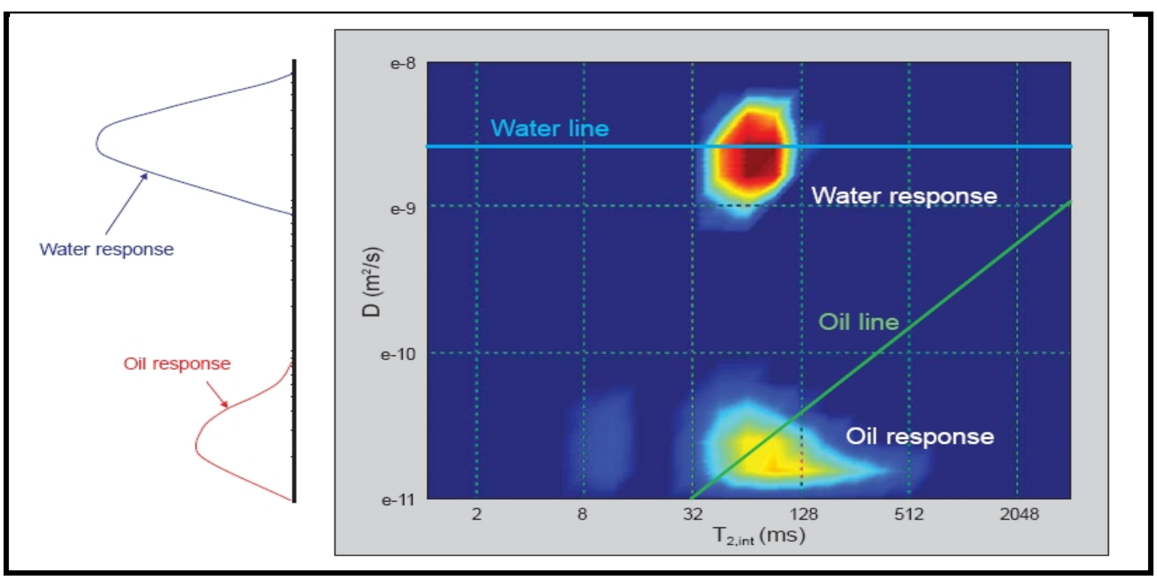


Fig .4 D vs. T2, 2D NMR image, crossplot of D spectrum and T2 spectrum

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.

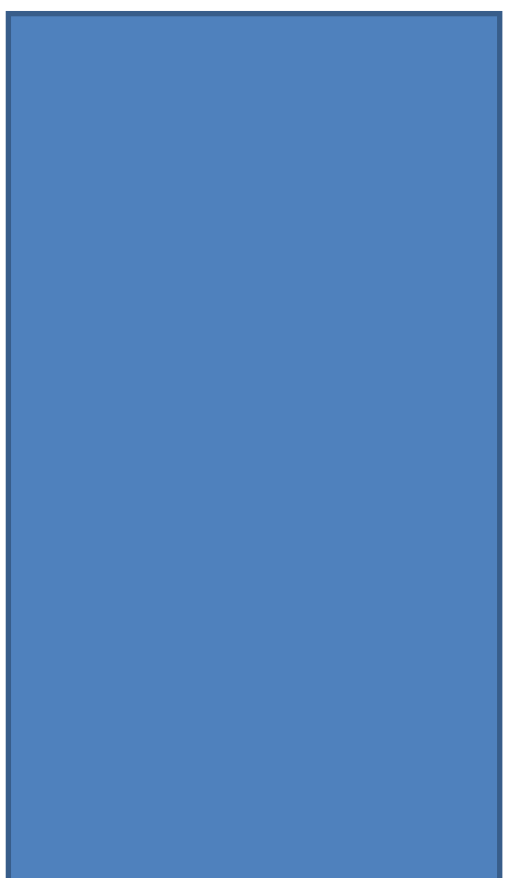
Because water molecules are typically smaller and more mobile than the hydrocarbon molecules in crude oils, the water signal decays faster than the oil signal for long-echo spacings (Akkurt, R., Vinegar, H., Tutunjian, P., and G uillory, A., 1996). By inverting a specially designed suite of NMR measurements with different echo spacings, the MRF method separates brine and oil signals (Fig. 4-6) even when the T2 distributions completely overlap.

Field Examples

Two examples of field logs from Mumbai High Basin, Western offshore, 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.

NMR Case study Well-X1

The major challenge in Well-X1 was the fluid identification and quantification in the interval 2290 – 2295 where there is a sudden drop in resistivity (Fig.5). Based only on conventional log analysis, it is not possible to accurately discern and quantify reservoir saturation in this interval. However, CMR-MRF analysis resolved the enigma of low resistivity in this well and helped in identifying and quantifying the correct fluid type. Based on this study, the interval 2290 -2295 was having flushed zone oil saturation around 27%. The interval was perforated and produced oil.



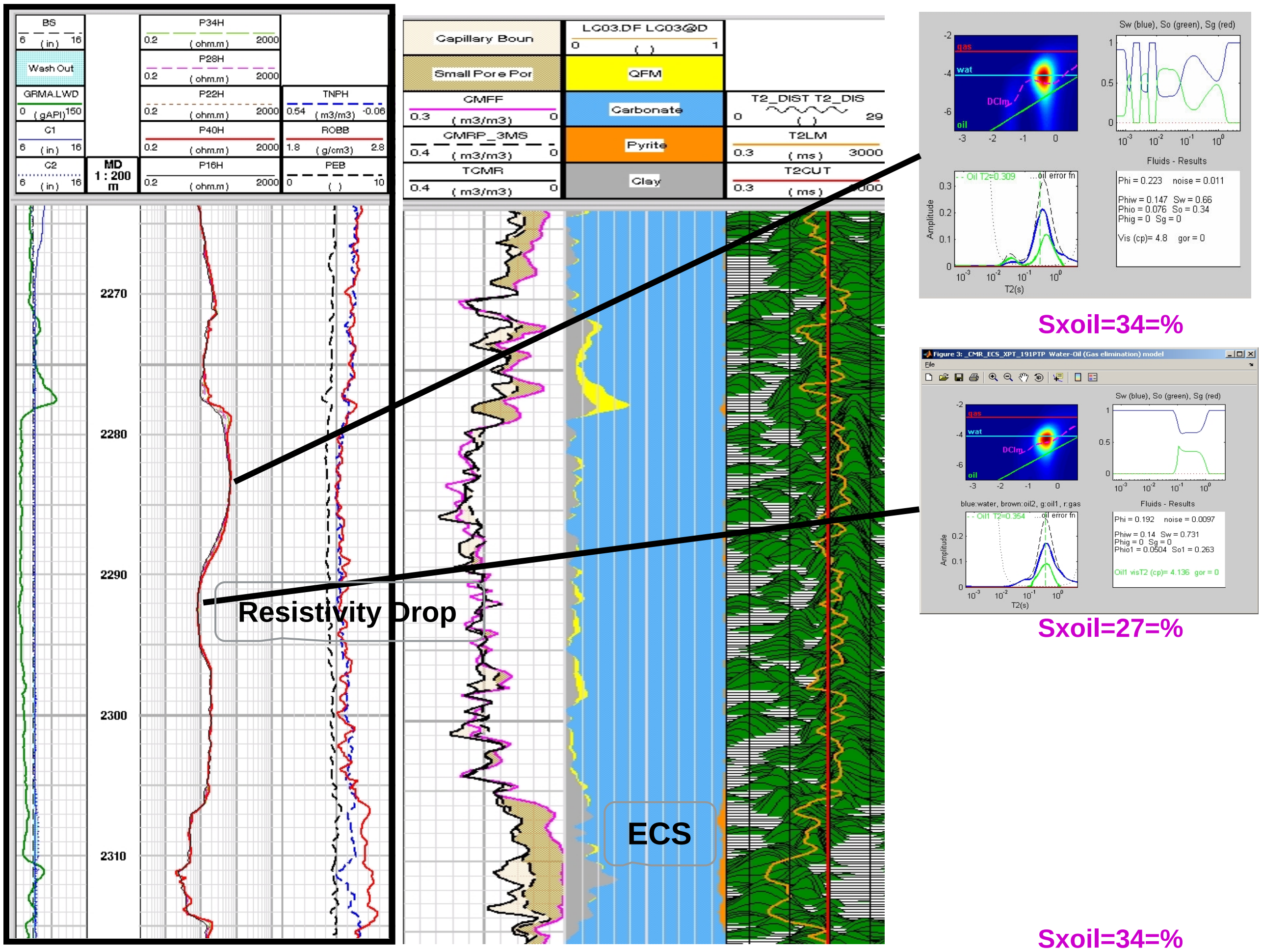


Fig.5 CMR-MRF analysis resolved the enigma of low resistivity Left is the conventional log suit, middle is the ECS log and NMR T2 distribution. Right most is the diffusion map with the colored circle defining the spread of the data.

NMR Case study Well-X2

The major challenge in Well-X2 was the fluid identification and quantification for the interval 1483 – 1485 (Fig.6). Based only on conventional log analysis, 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 for the said interval (Fig.7). Based on this study, the said interval was having flushed zone oil saturation around 48%. The interval was perforated and produced oil.

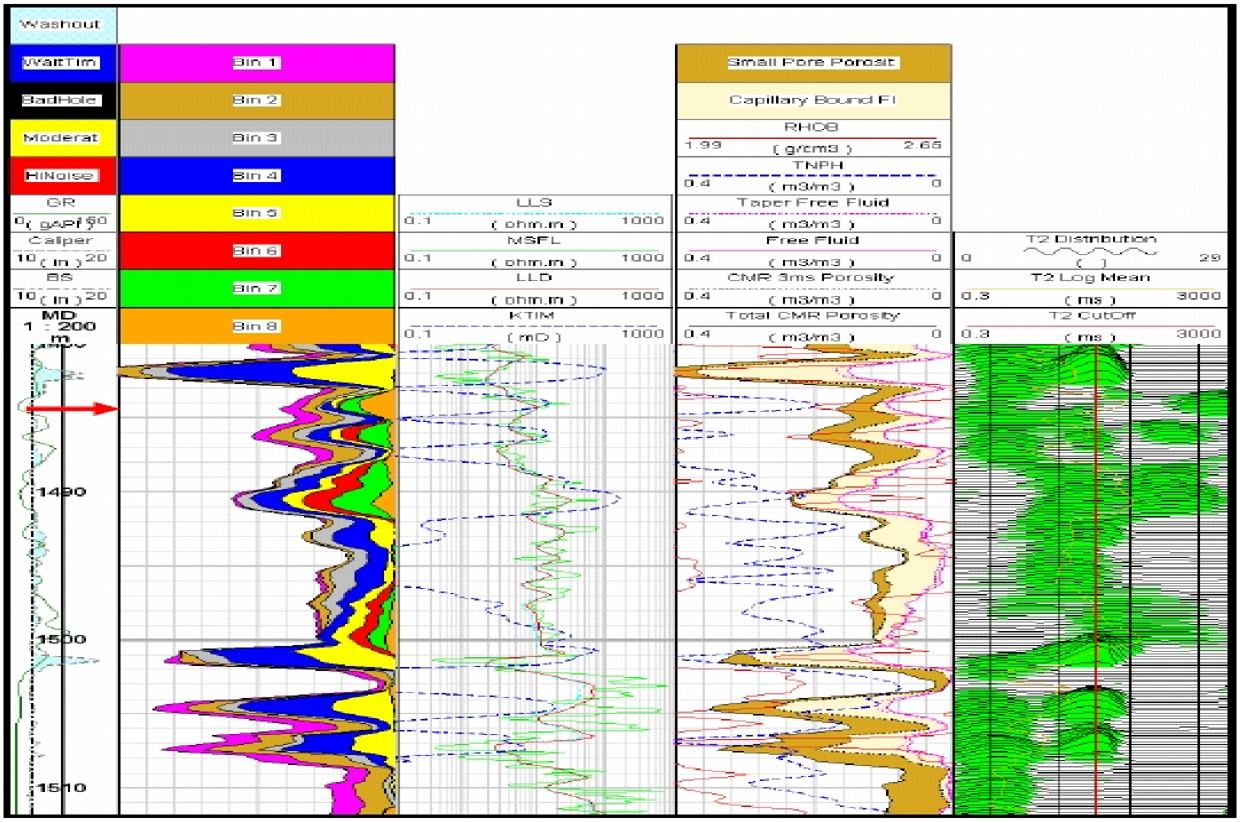
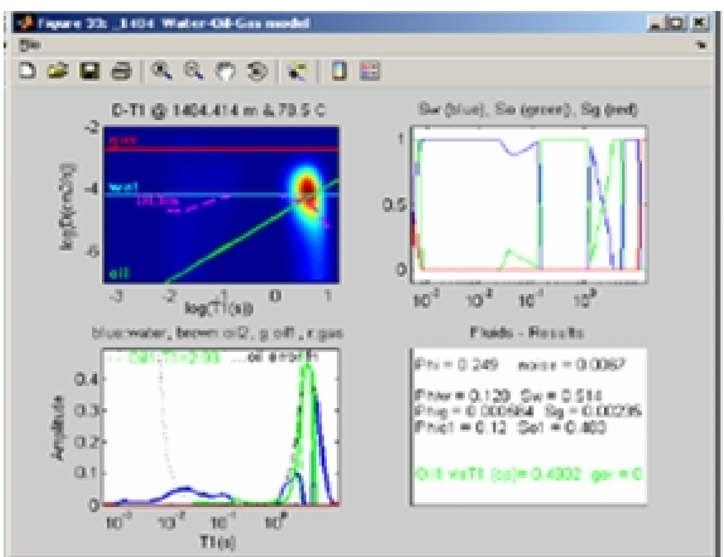


Fig.6 NMR log suit for the Well-X2. MRF data was acquired by the CMR tool @ 1484.5 m



Water-Oil-Gas ModelUsed

Flushed Zone So ~ 48%

Total Porosity ~ 24.9 p.u.

Fig.7 MRF analysis of the data acquired by the CMR tool@1484.5m MRF station point analysis proved oil

Results and Discussion

The analysis provides accurate results in low 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 resistivity. MRF station measurements were made at depth 2292.5 m. The points are falling on in between water line

& oil line (Fig.5). 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 1484.5 (Fig.6). Based on this study, the said interval was having flushed zone oil saturation around 48% (Fig.7). The interval was perforated and produced 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 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 Multi-Dimensional NMR techniques greatly increase the accuracy of reservoir fluid characterization and saturation determination in oil fields in western offshore of India. It has been found that the analysis provides accurate results in case of Low Resistivity Low Contrast reservoirs.

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