Enhanced Characterization of Heavy Oil Bearing Unconsolidated Clastic Reservoir of Kuwait by Integrating Dielectric Dispersion and Diffusion-Based NMR*

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Abstract

Characterization of heavy oil reservoirs and their fluid viscosity is critical to assess the reservoir potential, identify the sweet spots, define the reservoir producibility, design the recovery strategies, and help on the production prediction. A robust workflow, integrating the latest advances of dielectric dispersion and diffusion based-NMR measurements, was developed for characterizing the heavy oil reservoirs and understanding its fluid complexity. This paper describes the workflow applied to the heavy oil bearing unconsolidated shaly-sand reservoirs of Kuwait, which show vertical and lateral variation in viscosity, in addition, to the variation in permeability and irreducible water volumes required for enhanced production prediction and simulations. The diffusion NMR measurements were introduced to define the oil signature and fluid volumes. Although, this advanced NMR technique is sensitive to fluid types and oil viscosity, it lacks in distinguishing bound water and heavy oil signals. To overcome this challenge, the dielectric dispersion measurement was introduced to aid the NMR interpretation. The dielectric logging was used to identify the hydrocarbon bearing zones and quantify the total water volume regardless of the formation water salinity and the rock electrical properties, taking advantage of its resistivity-independent saturation approach. The quantitative water volume from dielectric was used to constrain the bound water volume and fine-tune the water and oil NMR cutoffs of the Diffusion-T1-T2 NMR approach. This has, consequently, enhanced the quantification of the oil volume from the diffusion NMR approach and reliably estimate its viscosity. Over the zones with shallow invasion, as is the case in

most viscous oil reservoirs, the multiple-spacing dielectric measurement allows determination of accurate flushed zone water saturation, enabling direct detection of movable hydrocarbon. This, in addition, to the use of the multi-frequency dielectric measurement to provide an in-situ estimate of the Archie's parameters where the core plugs and laboratory rock analysis are very difficult to obtain because of the unconsolidated nature of the rock. The workflow, applied on a number of wells, has provided enhanced characterization of the unconsolidated clastic reservoir and its heavy oil property. The results have been benchmarked with the laboratory fluid analysis data (PVT) over the same interval and a very good agreement has been demonstrated.

Reference Cited

Freedman, R., S. Lo, M. Flaum, G.J. Hirasaki, A. Matteson, and A. Sezginer, 2001, A New NMR Method of Fluid Characterization in Reservoir Rocks: Experimental Confirmation and Simulation Results: SPE Journal, SPE 75325, v. 6/4, p. 452-464.

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Kuwait Oil Company

Schlumberger

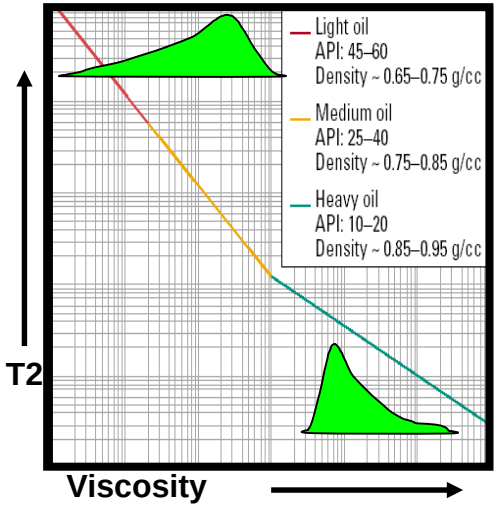
Outline

- ❑ Heavy Oil Reservoir Characteristics and Challenges
- ❑ NMR Challenges in Heavy Oil Reservoir
- ❑ Dielectric Dispersion Introduction
- ❑ Dielectric/NMR Integration
- ❑ Case Study Results
- ❑ Conclusions

Heavy Oil Reservoir Characteristics and Challenges

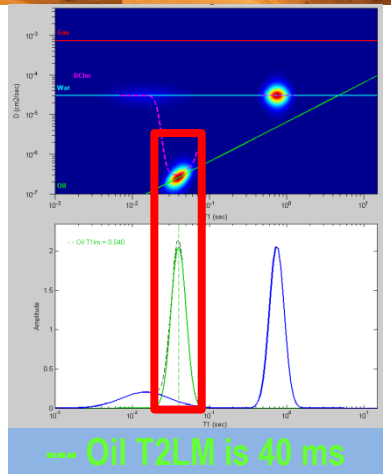
- Downhole oil viscosity is directly related to oil mobility
- Oil viscosity controls recovery method
- Oil viscosity is key simulation input for thermal recovery techniques
  - Large impact on capital and operating costs
- Well completion uncertainty: Movable oil, Lateral & vertical viscosity variation
- Highly unconsolidated clastic formation where core measurements are difficult to obtain
- Variable formation water salinity making the conventional saturation estimate unreliable

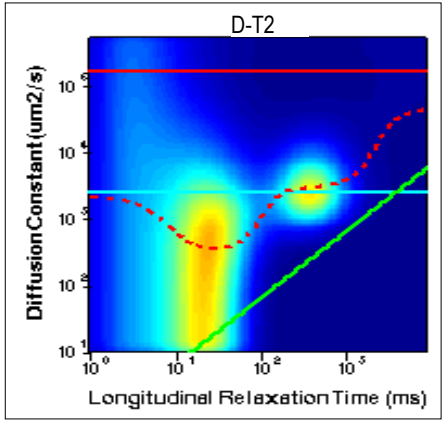
NMR Challenges in Heavy Oil Reservoirs



$$\eta = \frac{aT}{T_{2LM}(oil)\, f(GOR)}$$

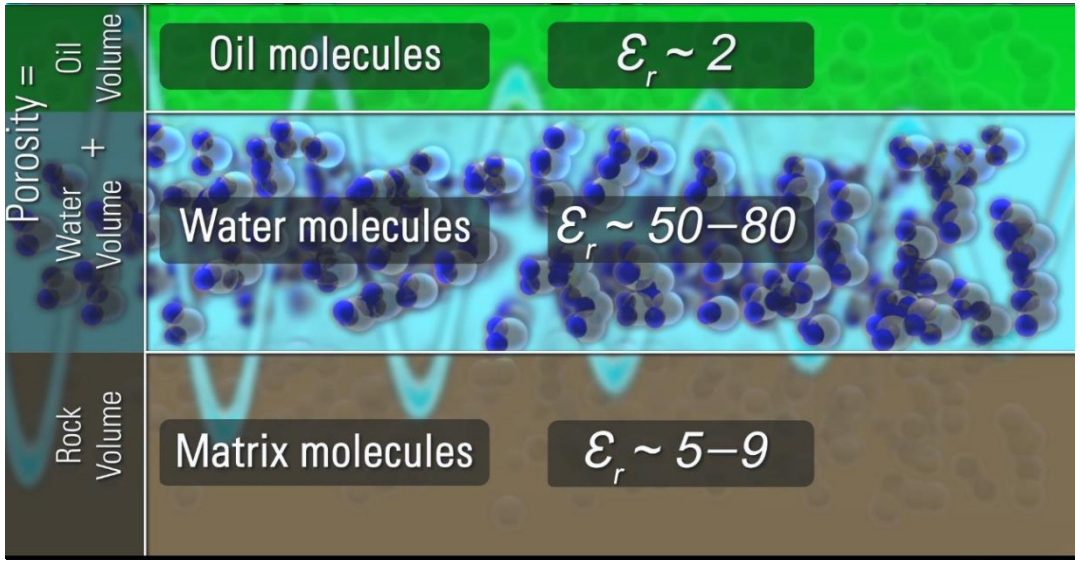
Constituent Viscosity model, Freedman, 2001



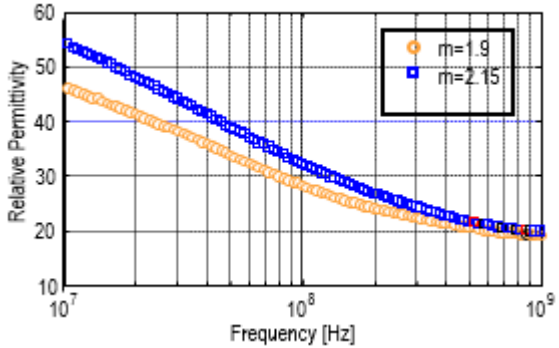


- Bound water overlap heavy oil
- Reduced T2 sensitivity
- Surface (wettability) effect → shortened oil T2
- SNR and so on…

Dielectric Dispersion for Direct Water-filled Porosity Estimate

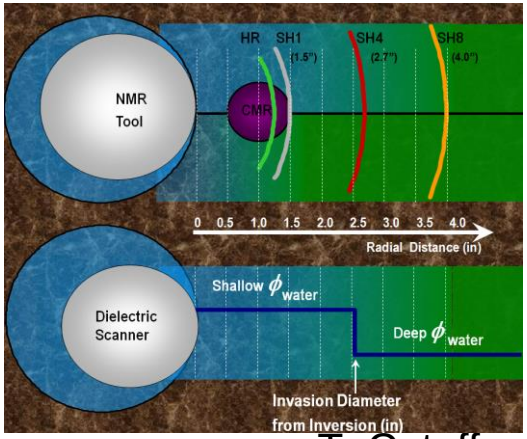


Dielectric Dispersion



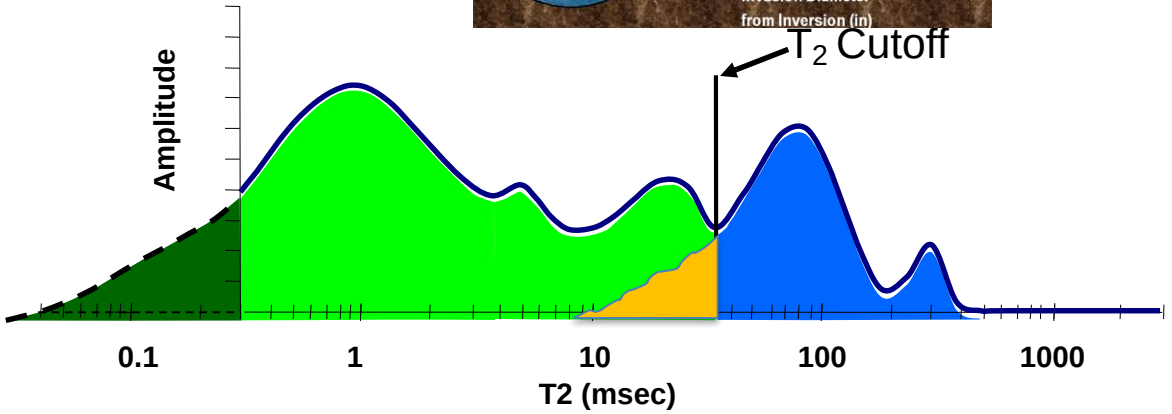
Dielectric Dispersion and NMR Integration

- Dielectric tool provides an accurate water-filled porosity
- Dielectric tool has similar DOI as the diffusion-based NMR



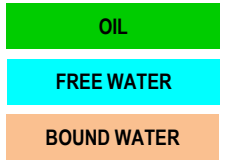
Integration Approach

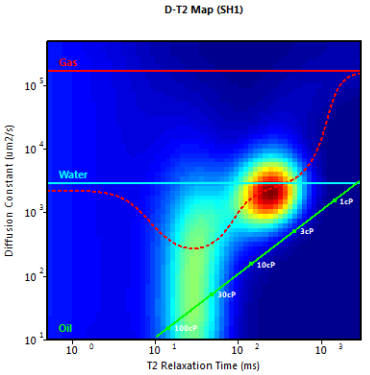
- Invisible oil
- Free water
- Heavy Oil + Bound water
- Bound Water



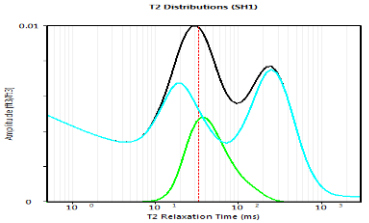
Viscosity using Integrated Workflow

- Heavy Oil + Bound Water fall below the 33 ms cutoff (Considered all bound fluid)
- Dielectric aids in adjusting the Heavy Oil volume
- Total volume of water from NMR matches Dielectric dispersion porosity
- Volume of oil includes heavy oil and viscosity is therefore enhanced

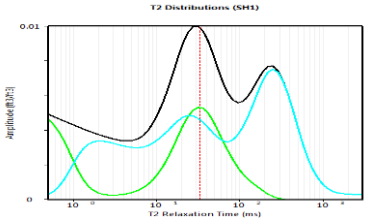




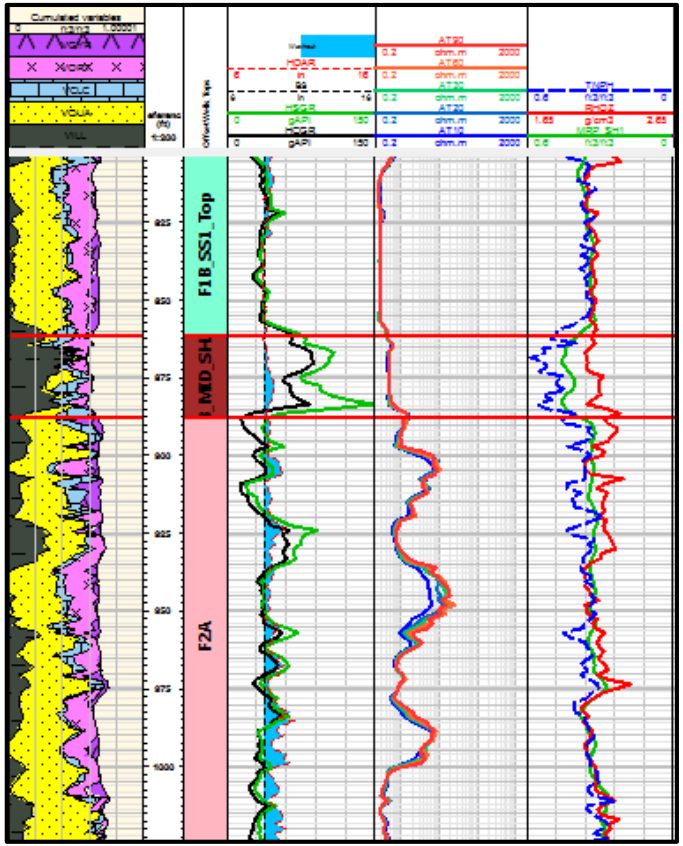
Before Dielectric



After Dielectric

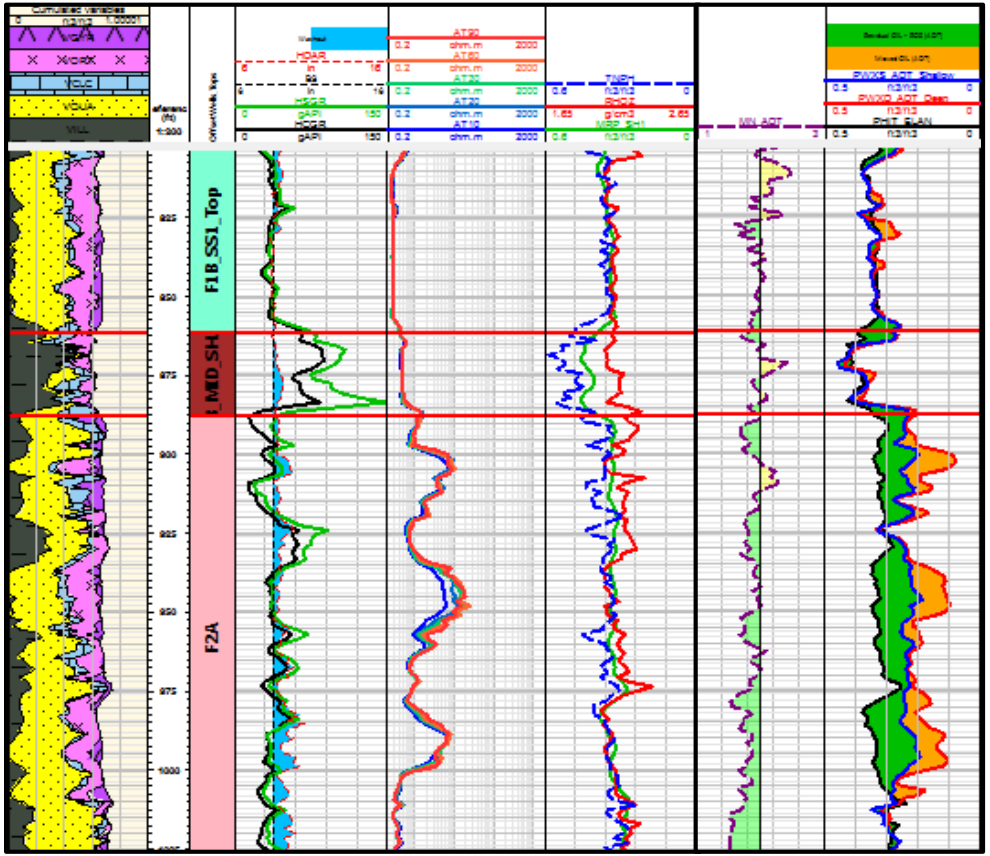


Case Study from Kuwait – Basic Measurements



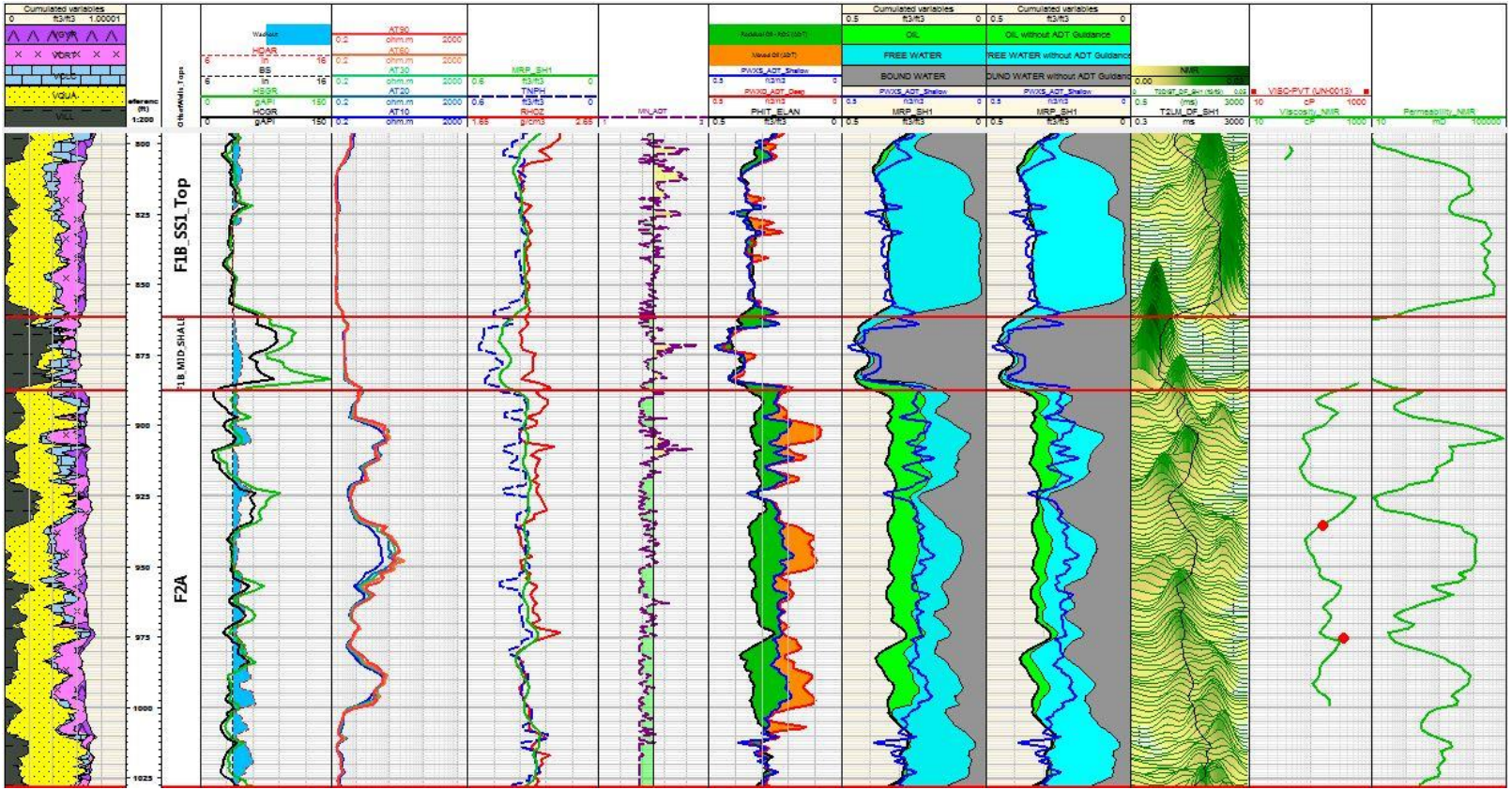
Basic measurements are showing relatively complex clastic formation. The resistivity is showing invasion signature too

Saturation Evaluation Using Dielectric Dispersion



- Dielectric oil volume estimate independent of the resistivity -based approach.
- Movable vs residual oil volume quantification providing inputs on production assessment.
- Continuous texture variation outputs where core measurements are difficult to obtain.

Integrated Dielectric – NMR for Improved fluid typing and viscosity estimate



Conclusion

- Dielectric/NMR integration is very useful for HO reservoir characterization of the unconsolidated clastic reservoir.
- Dielectric provides a reliable estimate of the oil saturation independent of the conventional resistivity models. It also provides the oil movability which is a key element for the HO reservoir to manage its production.
- NMR/Dielectric integration improved the viscosity estimate of the oil and the rock permeability, along with the detailed fluid typing. Good agreement with PVT analysis was demonstrated.