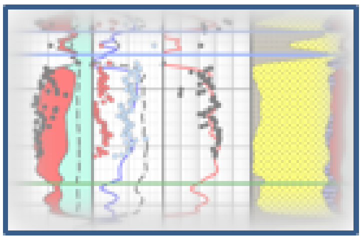


Resistivity Free Saturation – One Day Seminar

LPS

Thurs 13th December 2018

The Geological Society, Burlington House, London

LPS One Day Seminar - Resistivity Free Saturation - Thurs 13th Dec - Geological Society					
	Start time	End time	Presenter	Affiliation	Title
	08:45	09:15	Registration		
	09:15	09:25	Mike Millar	LPS President	Welcome address
1	09:25	10:00	Mike Millar	Independent	What's Wrong with Archie? A perspective on why we need Resistivity-free Saturation
2	10:00	10:35	Alan Johnson	Integrated Petrophysical Solutions Ltd	The Value of Saturation Height Functions
3	10:35	11:10	Craig Lindsay	Core Specialist Services	Accurate Reservoir Water Saturation from Core – Fact or Fiction?
	11:10	11:40	Break		
4	11:40	12:15	Adam Moss	AKM Geoconsulting Ltd	How to Obtain Primary Drainage Capillary Pressure Curves and Predict Transition Zone Water Saturation Using NMR T2 Distributions
5	12:15	12:50	Mathias Horstmann -	Schlumberger	Estimation of Sw from NMR T2LM
	12:50	13:40	Lunch		
6	13:40	13:40	Pedro Romero	Weatherford	Determining Water Saturation in Permian Basin Intercalated Reservoirs Using NMR Log Data
7	13:40	14:15	Geoff Page	Baker Hughes	Resistivity free saturations – Dielectric
8	14:15	14:50	Nicklas Ritzmann	Baker Hughes	Controlled Mud Gas Analysis Enables Resistivity Free Petrophysical Evaluation of the Reservoir
	14:50	15:20	Break		
9	15:20	15:55	Chiara Cavalleri	Schlumberger	An excursion through water saturation methods from cased hole logging
10	15:55	16:30	Roberto Nardiello	Baker Hughes	Advanced methodologies for fluid characterization and saturation evaluation behind casing
	16:30	16:35	Dawn Houliston	LPS VP Technology	Closing remarks
	17:10	Onwards	President's evening - Kings Head		

£150 for delegates (Speakers exempt)
(LPS is not VAT registered)
Students can register for free
Includes lunch and post-seminar wine and savouries.
Doors open at 9am.
For more info or to register for this event please visit ***www.lps.org.uk/events/***

Mike Millar – Independent

What's Wrong with Archie? A perspective on why we need Resistivity-free Saturation

For the last 75+ years resistivity logs and the Archie equations have been the 'go-to' method for quantifying water saturation in open-hole. But Archie was the first to admit that his equations do not cover all situations;

"it is apparent that much care must be exercised in applying to more complicated cases the methods suggested. It should be remembered that the equations given are not precise and represent only approximate relationships." (Archie 1942).

We will take a look at what information we really need to acquire in our boreholes, and why a full and quantitative understanding of fluid saturation is so important to the safe and economic development of hydrocarbon reservoirs.

We will review situations where Archie's equations are less than effective, and where they stop working altogether. We will then briefly introduce what other techniques and tools are available for calculating saturation in open and cased holes.

Archie, G.E. (1942) The Electrical Resistivity Log as an Aid in Determining Some Reservoir Characteristics. Transactions of the AIME, 146, 54-62.

Alan Johnson – Integrated Petrophysical Solutions Ltd

The Value of Saturation Height Functions

For many, the saturation height function is a necessary evil, seen as the only way of translating our log derived water saturations into the geologically-based 3D static or dynamic models. For this near-final step in the petrophysical evaluation process the saturation-height model may well be calibrated against the log-derived water saturations themselves, with the function being based on log-derived porosity and/or permeability and true vertical height above the free water level. The obvious advantage of this approach is the generation of water saturations in the 3D model which reflect, as closely as possible, the results calculated from logs.

This presentation will aim to highlight several advantages of investigating a non-log-based saturation height function i.e. functions based on core derived capillary pressure data.

While there is a common argument is that a log-based function is obviously more likely to match (resistivity) log saturations and that the introduction of independent saturation data only adds to uncertainty, this talk will present some examples where the independent capillary derived saturations served to identify flaws in the initial log analysis which would otherwise have gone unnoticed. Capillary based saturations therefore serve as a useful, if not essential, quality control step in the evaluation process.

In addition, the talk will also discuss how the adoption of a particular form of saturation- height function, a modified Leverett-J presents, in combination with log-derived saturations, a simple graphical solution to the estimation of free water levels in the absence of actual well penetrations or undepleted pressure data in the hydrocarbon and water columns.

Craig Lindsay - Core Specialist Services Limited

Accurate Reservoir Water Saturation from Core – Fact or Fiction?

Or

There and Back Again … The Return of the Retort

In the beginning there was the retort, then came the Dean Stark. Just when you thought it was safe to go back in the core analysis lab ... we have the return of the retort! What goes around comes around!

Derivation of water saturation data from reservoir core can potentially provide a robust benchmark value against which to anchor values derived from log evaluation & saturation height modelling.

Methods have changed over the years and these will be described from the personal experience of the author.

Dean Stark is an elegant and accurate procedure for quantifying the water content of substances including porous media. The Dean Stark procedure can only provide accurate water saturation on core if the correct procedures are followed during coring, core recovery, wellsite core handling and transportation, core sampling, water extraction and data calculation.

Saturation data from core is often misunderstood or used inappropriately. What we DO and what we DO NOT get is clearly explained.

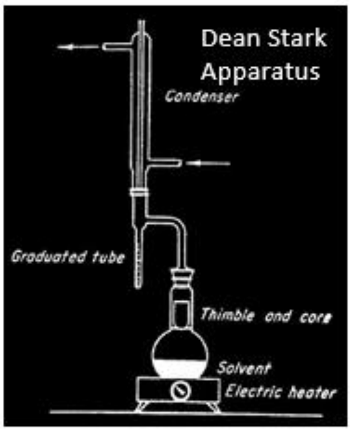
This presentation provides guidance as to how best practice can ensure that robust water saturation values can be obtained from core.

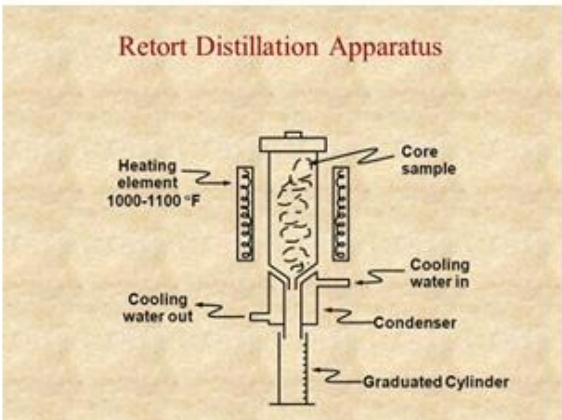
We also look at what situations are optimal and sub-optimal for obtaining reservoir representative water saturation from core. How important is core water saturation and how accurate does it need to be?

Examples are shown from studies in which core water saturation played a highly important role in reservoir characterisation and asset development.

Dean Stark has limited application in unconventionals; hereby the return of the retort!? Learnings from recent research is shown to demonstrate these applications.

The presentation closes with an idea for a simple check to determine if clay bound water is retained or removed during the Dean Stark procedure.





Dr Adam Moss - AKM Geoconsulting Ltd

How to Obtain Primary Drainage Capillary Pressure Curves and Predict Transition Zone Water Saturation Using NMR T2 Distributions

Nuclear Magnetic Resonance (NMR) derived T2 distributions have long been recognised as providing valuable information about pore size and fluid distribution in reservoir rocks. Conversional methods for deriving water saturation from T2 distributions use the T2 cut-off method, this determines the bound fluid saturation. The T2 cut-off method models water saturation at a theoretical irreducible water saturation, it does not account for transition zone water saturations.

The fully brine-saturated sample T2 distribution can be thought of as a 'pseudo' pore-size distribution. This property has been used by researchers to convert T2 distributions to capillary pressure curves. Single conversion factor/scaling factors have been used, but this assumes that the pore space has a single surface relaxivity value and resembles a bundle of capillary tubes. Methods using variable scaling factors have been published. A variable scaling factor takes account of variable surface relaxivity throughout the pore space and the existence of pore body restrictions/throats.

This work investigates the use of core calibrated variable scaling factors to derive capillary pressure curves from log NMR T2 distributions in both a heterogeneous carbonate and a sandstone reservoir. The resulting capillary pressure curves are used to predict water saturation versus height in the reservoir column.

The variable scaling factor functions are obtained using mercury injection primary drainage capillary pressure curves and brine-saturated T2 distributions from plug samples. The scaling factor functions can be used to convert the NMR log data to modelled mercury injection curve at every depth interval. The resulting capillary pressure curves are converted to reservoir conditions using special core analysis and fluid property data. Knowing the height above free water level, the water saturation at each depth can be estimated. The resulting water saturation is compared with the NMR log T2 cut-off water saturation and log water saturation from resistivity-based models.

An attempt has been made to derive a global model to predict capillary pressure from NMR T2 distributions in reservoir sandstones. To do this we use SCAL data from the ART NMR Sandstone Rock Catalogue to obtain core calibrated variable scaling factors for 174 reservoir sandstone samples. The samples used have a wide variety of mineralogy, diagenetic overprints and cover six orders of magnitude in absolute permeability. A global model to predict capillary pressure from NMR T2 distributions in reservoir sandstones has been developed using correlations between the variable scaling factors and permeability.

Moss, A.K., Benson, T. and Barrow, T., "An Investigation into Different Correlation Methods between NMR T2 Distributions and Primary Drainage Capillary Pressure Curves Using an Extensive Sandstone Database" presented at the International Symposium of the Society of Core Analysts 2018, Paper SCA2018-10

Brandimarte, F., Eriksson, M. and Moss, A., "How to Obtain Primary Drainage Capillary Pressure Curves Using NMR T2 Distributions in a Heterogeneous Carbonate Reservoir. Presented at the International Symposium of the Society of Core Analysts 2017, Paper SCA2017–66.

Mathias Hortsmann - Schlumberger

Estimation of Sw from NMR T2LM

We used conventional logging while drilling (LWD) nuclear magnetic resonance (NMR) transverse relaxation time (T2) data to estimate virgin zone water saturation (*Sw*) in environments challenging to conventional resistivity based evaluation: such as fresh water, high shale content, varying or unknown water salinity, and uncertain Archie parameters (a, m, n). It is important to stress the use of while drilling data to minimize the effect of invasion, although this can be corrected.

The technique relies on the T2 log-mean (*T2lm*) equation written for a binary fluid system of water ($T2lm_w$) and hydrocarbon ($T2lm_{hc}$): $T2lm = T2lm_w^{Sw}\, T2lm_{hc}^{(1-Sw)}$. It is trivial to expand the equation to accommodate more fluids such as filtrate or bound water. The water endpoint, $T2lm_w$, is obtained from the fluids-substituted 100% water endpoint corrected for partial saturation. The hydrocarbon endpoint, $T2lm_{hc}$, if unknown, can be estimated from the difference between the original T2 distribution and the 100% water T2 distribution after fluids substitution.

The salient point is that computing *Sw* from the *T2lm* equation is always possible unless the fluids endpoints are identical, in contrast to computing saturations from the fluids volumes obtained by partitioning the T2 distribution. For example, we have found that *Sw* can be estimated reliably even when $T2lm_w$ and $T2lm_{hc}$ are in the same decade of T2 relaxation time, while their respective T2 distributions are inseparable. Moreover, the technique is visual and straightforward to quality control, i.e. *Sw* is the weighted distance of the log data point with respect to the water endpoint and the hydrocarbon endpoint in the logarithmic space.

The first example is laboratory data of a sandstone, first saturated with water, then de-saturated with kerosene at fixed saturation steps. The controlled measurements allow the explanation of the algorithms used in the Sw from NMR T2 workflow.

Several field examples demonstrate the cases of: a) water relaxing *faster* than hydrocarbon ($T2lm_w < T2lm_{hc}$) such as conventional reservoirs with light oil, b) water relaxing *slowe*r than hydrocarbon ($T2lm_w > T2lm_{hc}$) such as unconventional reservoirs or heavy oil reservoirs, c) varying hydrocarbons such as reservoirs with a gas cap above oils with various API gravity, and d) varying water salinity such as waterflooded reservoirs in mature fields. In the examples, we compare *Sw* determined from NMR T2 with *Sw* determined from deep resistivity, pulsed neutron capture sigma (that is independent of a, m, n) and joint-inversion of resistivity-sigma (that is used in the case of unknown water salinity) to show the viability of the new technique when conventional approaches fail to deliver reliable answers.

Pedro Romero - Weatherford

Determining Water Saturation in Permian Basin Intercalated Reservoirs Using NMR Log Data

Alternating conventional and unconventional reservoir layers in the Permian Basin challenge the acquisition, processing, and interpretation of water saturation (Sw) using nuclear magnetic resonance (NMR) log data. A new-generation NMR wireline tool addresses these challenges using a specially designed conventional-unconventional activation sequence to enable construction of optimized maps of Longitudinal–Transversal Relaxation times (T1-T2 maps) at regular depth intervals.

T1-T2 maps are used to compute level-by-level Sw based on a multicomponent fluid model with appropriate statistical properties. Each spot in the T1-T2 space represents a fluid component from which a volume fraction is calculated. Integrating the volume fractions gives the total porosity. Because of the diverse relaxation mechanisms in the conventional and unconventional layers, oil spot positions with T1/T2 values greater than two reflect either viscosity (for bulk relaxation) or pore-size distribution (for surface/volume relaxation). Water tends to be close to the 1:1 T1/T2 diagonal line with T1/T2 values less than two. Low permeability means that mud-filtrate invasion does not appear on the T1-T2 maps.

NMR porosity matched expected values based on core and density-neutron log analysis. NMR fluid-typing-derived Sw—including clay bound water (CBW), capillary bound water (BVI), and free water—matched values from tested intervals. Results are in good agreement with reference values from production and core data within an uncertainty of one standard deviation. The resolution of fluid components in intervals where the components overlap can be enhanced by changes in the inversion parameters and map-grid dimensions.

This methodology for conventional-unconventional data acquisition followed by a multimodel approach for fluid typing will be applied to other wells. It enables a more accurate assessment of water saturation, especially when intercalated layers of conventional and unconventional reservoirs are present

Geoff Page – Baker Hughes

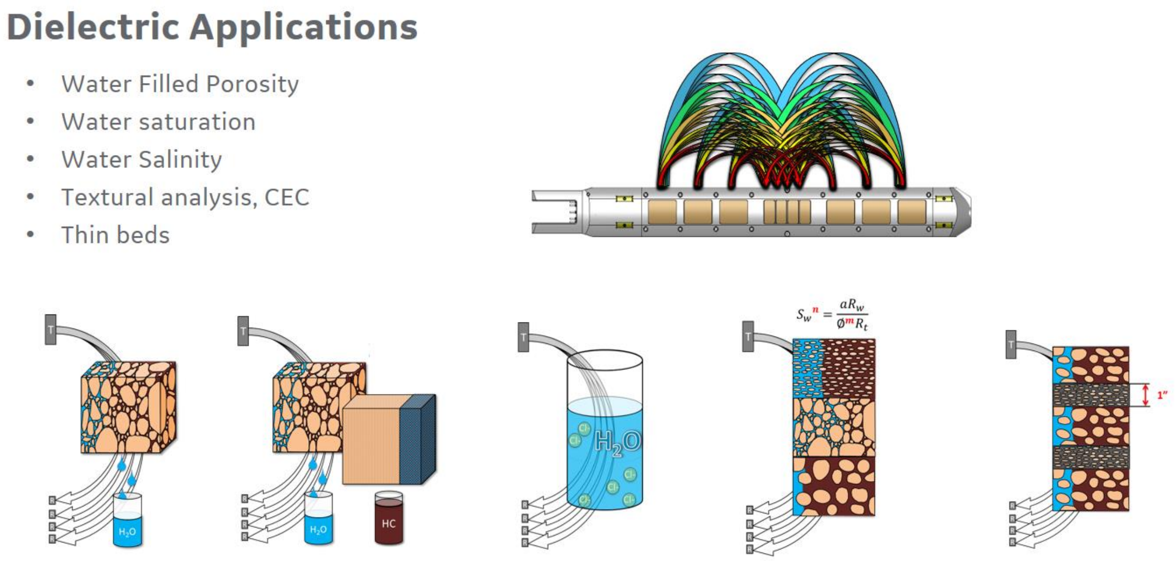
Resistivity free saturations - Dielectric

Resistivity measurements rely on a difference in conductivity between saline water and hydrocarbons, however if the water is fresh and is also resistive the uncertainty in calculated Sw increases.

Dielectric measurements use very high frequency electromagnetic energy to determine the "polarizability" or dielectric constant of the fluids (and rocks). The physical shape of a water molecule means that it has a high response compared to hydrocarbons, for any salinity, thus allowing water saturations to be calculated even for very fresh formation water.

This presentation will cover the basic principles of the measurement, what it is responding to, and how saturations are calculated. Instruments have been available to make dielectric measurements for several decades, however recent "Array" multi frequency tools also allow the estimation of many of the interpretation parameters reducing uncertainties further.

In a similar way to resistivity calculations starting with the simple "Archie" model and developing into more complex saturation models; Dielectric interpretation starts with "CRIM" and now a variety of different models are available for different formations.



Nicklas Ritzmann – Baker Hughes

Controlled Mud Gas Analysis Enables Resistivity Free Petrophysical Evaluation of the Reservoir

In cases where resistivity measurements and/or other log data are unreliable due to wellbore rugosity, deep invasion, measurement artefacts, tool failures or unavailable due to a high deployment risk; an independent measurement is needed to obtain accurate formation saturations.

Since the beginning of oil and gas exploration, surface logging technologies have been a crucial input for reservoir evaluation. Apart from geological, biostratigraphical and diagenetical information gas data are used for information on the fluid composition of the reservoir fluids and are continuously analysed. Mud gas data stands as an independent dataset against downhole measurements. By integrating the recorded gas concentration with the drilling information, such as the rate-of-penetration a saturation, volumetrics and permeability index can be calculated. Recent hardware development has improved data quality as well as density thus increasing the reliability of the base data significantly. This enables a semi to quantitative analysis of the hydrocarbon saturations and permeability trends of the formation. Furthermore, a correction for recycled gas reduces the effects from artificially elevated gas concentrations by residual hydrocarbons in the drilling mud.

We present a recent case study from a clastic reservoir from the North Sea, United Kingdom demonstrating an alternative method for a full reservoir characterization using mud gas data. We demonstrate the benefits of using high end mud-logging services over standard mud-gas data and compare all results to a standard environmental corrected resistivity derived saturation, as well as the saturations derived from a high-angle processing corrected true formation resistivity (Rt).

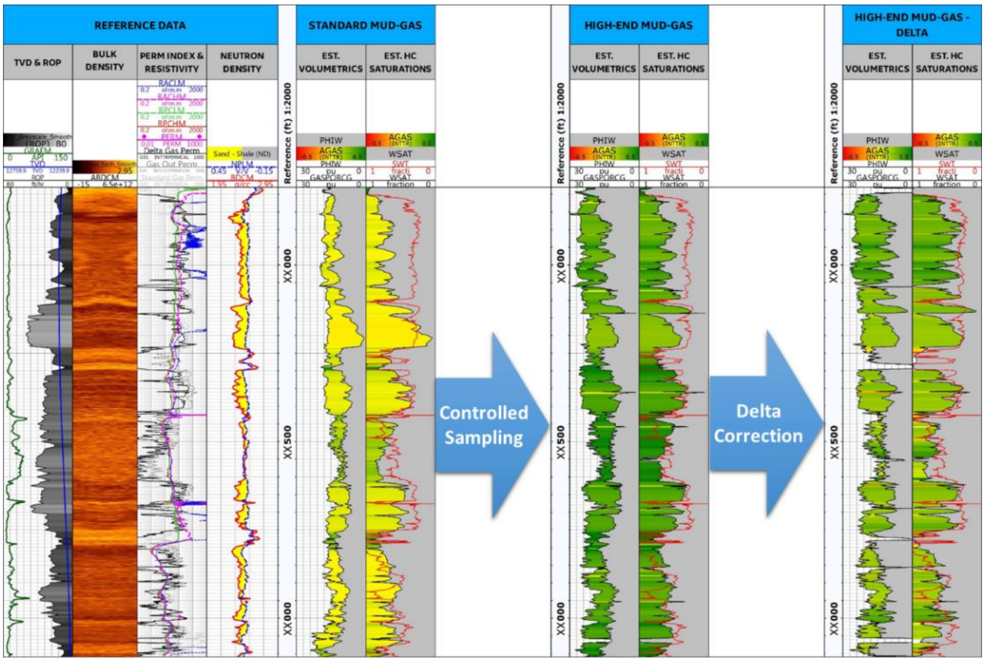


Figure 1: Showing the differences in saturation accuracy by using high-end mud-gas analysis services

Chiara Cavalleri - Schlumberger

An excursion through water saturation methods from cased hole logging

Cased-hole formation evaluation and saturation monitoring have a primary role on proper description of existing reservoir systems and definition of additional productive reserves' units. In the past few decades several approaches have been established to calculate water saturation in cased boreholes.

We discuss various methods for evaluating water and hydrocarbon volumes in different cased hole environments and formation types:

- Sigma which requires that the formation water salinity is sufficiently high and known
- Sigma combined to cased -hole resistivity which solves simultaneously for water saturation and water salinity when this is large enough, although does not need to be constant.
- Carbon/Oxygen ratio, a classical measurement for cased hole reservoir monitoring of oil content and fresh water conditions
- Total Organic Carbon measurement, from Total Carbon minus Mineral carbon (from capture and inelastic GR spectroscopy).
- Fast Neutron Cross Section new measurement (from inelastic Gamma Ray) which measures gas and quantify gas volume in low porosity rock together with Sigma and neutron porosity logs.
- Integrated approach which combine more measurements and techniques.

These alternative measurements have different advantages and ranges of application and, depending on the characteristics of the reservoir's formations, respective accuracies. The logging conditions and wellbore status also play a relevant role on the definition of the measurements, evaluation methods, and robustness of the computed answer.

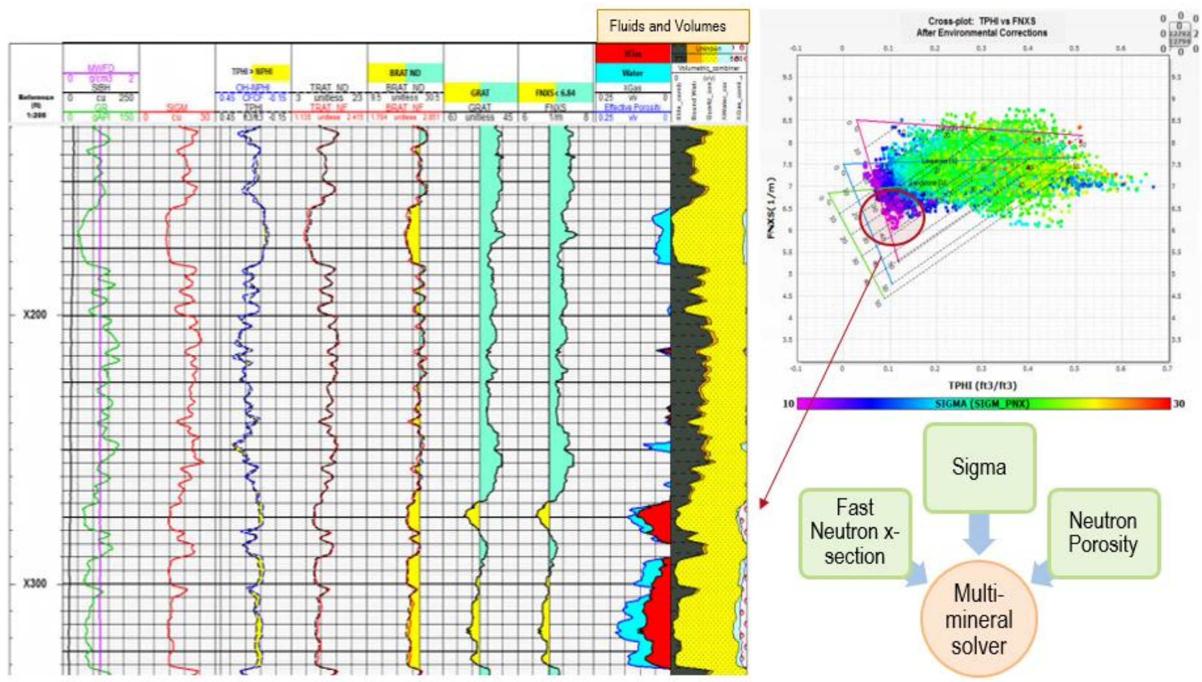


Figure 1: Log example: Standalone cased hole evaluation of gas volume and saturation in a producing field; the volumetric interpretation is by means of a linear solver with Pulse Neutron tool's sigma, Fast Neutron Cross-section, and neutron-porosity measurements.

Roberto Nardiello – Baker Hughes

Advanced methodologies for fluid characterization and saturation evaluation behind casing

Monitoring fluid saturations in producing reservoirs over time is critical for the effective exploitation of the resources. From this, important decisions can be made like, for example, set new contacts, perforate new producing intervals or plan workover activity depending on the fluid characterization. This saturation evaluation can be complex, depending on fluid phase presence.

In case of Gas-Water phases only, changes in the gas cap can occur due to depletion or contraction, or re-pressurization from water injection.

In case of Oil-Water phases, changes can occur due to production or water flooding.

For three-phase saturation, conventional methodologies estimated gas saturation using qualitative indicators or empirical transforms. An advanced 3-phase saturation evaluation is possible when gas saturation can be quantified using an independent measurement, bringing more clarity to the description of the reservoir and fluid saturations.

A preliminary study of reservoir properties and borehole environment is crucial to minimize uncertainties that can occur in saturation quantification. Well-specific Monte Carlo N-Particle (MCNP)-based forward modeling enables pre-job sensitivity analysis and provides the predicted theoretical measurement responses required for saturation analysis and log quality checks.

Depending on salinity range and oil properties, this application can combine either the carbon/ oxygen (C/O) analysis together with gamma ray ratio-based gas saturation techniques or can combine pulsed neutron capture data (sensitive to medium- light oil) again with gamma ray ratio-based gas saturation from the same data set to deliver three-phase fluid saturations. The two techniques involve using an innovative triangulation technique to simultaneously quantify water, oil and gas saturations.

This presentation will provide details of the measurement physics, data acquisition, triangulation interpretation methodology and field examples.