**Petrophysics 101: An Introduction to Production Geology and Cased Hole Logging**

**Thursday 5th March 2020**
The Geological Society, Burlington House, London

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Murtaza Amin – Tullow Oil

Applications of Cased Hole Logging over Well/Field Life

The term ‘well logging’ or petrophysical formation evaluation has been synonymous with open hole logging, i.e. logging immediately after drilling a well or a section thereof, with the drilling fluid still in the hole.

However, there are several applications for well logging after running casing to total depth and cementing, for petrophysical and non-petrophysical evaluations. Cased hole logs cannot replace open hole logs completely, as the decision to run casing in the first instance may require a log to be run in the well.

Petrophysical logging in cased hole requires specific corrections to be applied to the acquired data to account for the metal casing and the cement behind casing. Also, the depth of investigation into the well bore in the cased hole log would be lower than that of a corresponding open hole log due to the casing and cement in front of the formation.

There are several applications for cased hole logging right upfront in a well life, immediately after running casing and cementing, which can replace open hole logs. This could potentially save cost, by allowing the drilling rig to move off the well and logging carried out offline, but is also an important application where well bore stability is an issue and the bore hole cannot be kept open for long. Gamma Ray, Resistivity, density, neutron, sonic, etc. are all petrophysical logs that can be run in the cased hole environment early in well life and can replace some open hole logs.

There are several petrophysical cased logging applications later in well life like saturation logging to understand waterflood performance.

However, the majority of cased hole logging applications are non-petrophysical, both early in well life (e.g. cement bond evaluation, depth correlation) and in late well life (e.g. production logging, well integrity monitoring).

The value of cased hole logging can be demonstrated via a case study where there was significant uncertainty in the residual oil saturation in a significantly heterogeneous reservoir in an onshore location, where the results from a single well tracer test carried out in one well were compared with carbon-oxygen logging in another well.
Introduction to PLT logging

Production Logging is a wellbore data acquisition technique used in the oil and gas wells for many different applications such as: to determine the downhole zonal contribution of fluids, to investigate if there is any cross-flow from one reservoir to another, to identify low productive zones, to determine the near-wellbore skin using pressure transient analysis and more advanced applications of locating reservoir boundaries, distance to faults and lastly in leak detections. The production logging data is acquired by multiple sensors and typically; spinner(s), pressure, temperature, gamma-ray, collar locator, water holdup, gas holdup, caliper, fluid density. The combined use of these sensors helps to fulfill the key objectives. The data acquisition in deviated and horizontal wells require a more advanced version of the production logging tool to ensure proper evaluation of the flow dynamics can be made. This presentation will cover the key applications and components of a production log at the introduction level.
Matt Le Good - BP

What’s inside the loop? Schiehallion case study

The Schiehallion subsea development is one of the largest on the United Kingdom Continental shelf. The development comprises two fields; Schiehallion and Loyal, which are located approximately 200km west of the Shetland Islands in water depths of 300-500m.

The Schiehallion Field was discovered in late 1993 with a STOIIP of >2.3 billion barrels, developed under waterflood. Oil is contained in deep-water turbidite reservoir sandstones of Palaeocene T25 to T34 age with a combined structural-stratigraphic trap.

The modelling challenge has always been to integrate seismic, log and core data at an appropriate scale in the model. There is a requirement to represent the variability and distribution of net reservoir that will impact fluid distribution and dynamic behaviour after production start-up. Seismic data provide the only available spatial dataset that can inform the depositional elements and architecture away from well control. However, in the past there was an over reliance on seismic data alone to describe the container due to imaging limitations.

We present an example of an integrated and updatable workflow to populate net in the Schiehallion static reservoir models, following the redevelopment drilling campaign, using One Dimensional Stochastic Inversion (ODiSI) combined with a plausible geological description from well data. The updated models should represent an integrated view of the subsurface, covering a range of uncertainties and will provide one of the tools for infill well planning to support the continued development of the Schiehallion Field until 2022 and beyond.

Figure 1: Well Log showing how well logs, core data and seismic data have been integrated to improve the subsurface description within the model. Modelled heterogeneity more similarly matches the ‘package scale’ and will influence fluid distribution and dynamic behaviour during start-up.
Rebecca Holyer – BP

The Theory of Pulsed Neutron Logging and its Application in Saturation Mapping for Remaining Oil

During the production phase of reservoir management, a critical requirement to maintaining a healthy reservoir is understanding the changing distribution of fluids and being able to manage offtake production and injection to maximise long term recovery. There are various static and dynamic methods of fluids surveillance which are often integrated into an updated description of the subsurface. This talk will focus on pulsed neutron logging which, in certain logging environments and completion designs, is the best option for acquiring formation saturations behind casing.

The presentation will explain the fundamental physics of measurement of both Sigma and Carbon / Oxygen modes, from nuclear interactions to calculating fluid saturations from raw curves, while summarising their key sensitivities and sources of uncertainty.

A case study from the Rumaila field, Iraq, also gives a prime example of how valuable pulsed neutron saturation logs can be – here to the management of a mature, supergiant oilfield with complex reservoir architecture, under both fresh water injection and saline aquifer driven depletion. A vast amount of surveillance data is acquired, interpreted and integrated into a Saturation Mapping process each year. The final product visually maps the distribution of remaining resource across the field and is an essential tool for identifying new well targets, production-adding wellwork opportunities and optimising waterflood sweep efficiency.
John Bennett - Assala Energy

A case study in the evolving Oil Water Surface in a West African Oil Field

This case study looks at the shape of the dynamic Oil Water Surface as it moves upwards and horizontal producers start to cut water.

The field shape, reservoir quality, heterogeneity & anisotropy are as close to simple textbook examples as are likely to exist in the real world.

The well-established reservoir model predicted a flat and gradually rising Oil Water Contact, however cased hole Sigma and Production logs in horizontal wells did not match the existing dynamic model requiring a modified approach.

Together with the Cased Hole Measurement and Interpretations we also look at key moments in the teamwork & approval process.
Alejandro Schiuma - Weatherford

Multi Detector Pulsed Neutron Gas Evaluation in a Fractured Reservoir

The interaction of neutrons in reservoirs allows the identification of gas in both open hole and cased hole environments. Due to increasingly complex operations, problems during drilling wells and the need to evaluate the recovery processes in production wells, the industry has demanded the evolution of pulsed neutron technologies that allow characterization with greater statistical accuracy and reliability. However, quantifying the volume of hydrocarbons in the reservoir is often associated with significant uncertainty, especially in secondary porosity systems which limits the ability to make informed decisions regarding the well completion.

Pulsed neutron technology has evolved, and in the last 15 years gas has become vital to the economy. This evolution led to improved quality and quantity of detectors thus allowing a more reliable quantification not only of gas saturation through the pipe, but also of petrophysical parameters such as porosity and clay volume.

The methodology to be described was used in the evaluation of gas reservoirs with secondary porosity in the Southern basin in Argentina.

Specifically, one of the wells did not have open hole logs while a second well had a complete set. The second well was used to model and calibrate the data obtained through the pipe and then applied to the well without data. Pre-work modelling, successful operation with specific operational conditions, and the integration of determining interpretation factors are presented to support gas saturations in both wells in addition to the generation of porosity and clay volume curves in the well that did not have open hole data. After interpretation, a completion program was able to be developed with greater certainty based on the validated petrophysical calculations obtained through casing. This presentation refers to the methodology and factors taken into account in completing such a survey.”
Ambuj Tyagi – Perenco

Cased Hole Saturation: Finding Remaining Oil Potential in wells of mature basins

In present time when there is less exploration activity compared to the times when oil traded above $100 per barrel, it has become more important to find remaining oil potential in existing wells. That is where Pulsed Neutron cased hole logging is becoming more popular.

Pulsed neutron logs are used to acquire data in SIGMA mode and Carbon/Oxygen(C/O) mode. SIGMA mode is appropriate for formations where the formation salinity is greater than 50000 ppm and C/O mode is of utmost importance when there is an uncertainty in formation salinity due to water injection or if the formation water is comparatively fresh.

Pulsed neutron logs are used extensively to identify perforation targets in existing wells. These logs are used to monitor moved contacts both OWC and GOC. This helps in finding out the remaining oil in existing wells and producing the remaining oil is cost effective that too in present times of low oil price.

![Image of log data with annotations]

The example above shows the use of SIGMA log that was used to compute cased hole water saturation. Based on the Petrophysical evaluation the remaining oil interval highlighted on the plot was used as perforation targets in the well.
Mike Millar – Independent

Cased Hole Logs Determine Re-completion Strategy in a Challenging Reservoir

This case study will review why Chalk is a challenging reservoir, and highlight the importance of all the subsurface disciplines working together to ensure that enough data is collected to understand the reservoir and to build a robust economic and safe development. And why data should be continuously collected during the production phase.

In this study, the reservoir is an Upper Cretaceous to Lower Palaeocene Carbonate Micrite, Chalk, with high porosity but low permeability. Fractures and hardgrounds can be important influences on reservoir quality and reservoir connectivity. Enough data, in terms of logs, image logs, cores and pressures were collected to reliably estimate in-place volumes and the potential reserves.

The platform was off-set from the main structure to avoid shallow gas and the potential for subsidence. It also made it easier to drill the high angle and horizontal wells planned for this development. Image logs were acquired in most of the development wells to highlight the fracture zones and guide the final completion design.

The Completions were designed with built-in flexibility, using perforated liners, with isolation packers between perforations and sliding screens to give the flexibility to open or close intervals as production dictates. Data has been continuously collected during the production phase, with downhole pressure gauges, and regular cased-hole logging runs. This has allowed for better history matching and highlighted a work-over target where a water injector was 'turned around' to produce oil from a by-passed oil zone.
Kamaljeet Singh - Schlumberger

Perforating Gun Systems and Wellbore Dynamics

Perforations play a crucial role in oil and gas wells. Perforating activity is of the last activity in the well completion before the well is put on production or injection. The productivity or injectivity depend on the near-wellbore pressure drop, referred to as skin, which is a function of well completion type, formation damage and perforating gun system parameters. Perforating connects the wellbore with the reservoir; however perforating also damages formation permeability around the perforation tunnels. The gun design parameters – formation penetration, hole size, shot density and the phasing have a significant impact on the pressure drop near the well. A lot of research has been done over the last decades and still ongoing to optimize the gun design parameters and new wellbore dynamics to minimize the near-wellbore skin. The presentation will cover some of the above aspects of the perforating gun design and wellbore dynamics.
Robert Maddock - Altus Intervention

Well Integrity Logging – A Primer

Assured well integrity is a requirement for the safe operation of wells from the construction phase to well abandonment. An important factor in well integrity is the condition of casing and tubing from the reservoir to the well head. Is the pipe corroded, deformed or damaged? Is there a leak, where is it and what caused it? Is there scale build-up? If so, how much and does it restrict intervention access to a safety-critical valve? How do corrosion and scale build-up vary over time?

A variety of technologies are used in well integrity logging including electro-mechanical, magnetic, acoustic, temperature, pressure, spinner and resistivity sensors as well as downhole cameras. These cased-hole logs can be acquired in surface-read-out or memory mode, with conveyance methods including slickline, e-line, coiled tubing and tractor.

The presentation will show examples of corrosion and scale logging (including time-lapse surveys), leak detection, drilling-related casing wear and deformed & perforated liner examination. The main focus will be on multi-finger caliper logs but examples of companion down-hole camera, noise, magnetic thickness and leak detection logs will also be presented.

The basics of processing and important pipe integrity statistics – maximum penetration & maximum wall loss – will be outlined.

Although well integrity logs are commonly viewed as ‘commodity logs’, accuracy and precision for quantitative measurement is no less important than for other downhole logs. Some of the factors affecting accuracy and precision for different sensors, as well as ‘log quality’ will be discussed.

*Calibrating a multi-finger caliper*  
3D caliper image of DynaSlot™ punched pipe

*Dynaslot is a trademark of the DynaEnergetics company.*
Emma Smith – Baker Hughes

A variety of Techniques used for Casing Integrity and Cement Evaluation Determination

Casing and cement evaluation forms and integral part in the development or abandonment of any well. It is important that both the casing and the annular cement can withstand subsequent completion and production operations. Early determination of any integrity issues can therefore prove to be time and cost effective during the well’s life cycle and verification of both is prior to successful abandonment operations.

The primary purpose of cement evaluation is to determine the presence of absence of annular cement at a certain in a wellbore and to evaluate whether the cement is bonded to the casing, the formation, or both. A wide range of cement evaluation tools have been developed over the years, where the traditional cement bond logs are based on the compressive waver principle. The theory behind these will be explained, together with examples of such tools, their main features and benefits. Over the last few years, one has developed a tool based on the shear waver technology.

This is used to better identify lightweight cements, and the presence of micro-annulus. Both the compressive and shear based cement evaluation tools can be logged in combination with the multi-finger caliper. The caliper measures the radius, which can expose casing damage, corrosion and scale deposits. Together, these tools will provide a complete integrity and cement evaluation product. There is also the capability to acquire both integrity and cement bond data by the use of one tool, which gives an immediately available composite product. The theory will be explained, together with several examples.
Andrew Imrie and Beverley Heeley – Halliburton

Cased Hole Barrier Evaluation

The need for acceptable behind casing barriers is obvious in the oil and gas domain, not just for plug and abandonment but for the full lifecycle of the well. This presentation will cover the basics of understanding common wireline logging tools that are deployed for barrier evaluation - from tool functions through to the foundations of log interpretation. This will include acoustic, ultrasonic scanning and spectral noise logging tools. Together the properties of annular materials can be identified and flow patterns understood.

The presentation will focus on case study examples and cover both cement evaluation and natural barrier identification such as mobile halites or shales. Key quality control data, standard inputs and outputs of the tools, and the processing techniques used in the assessment of bond quality will be described. When analysing modern complex cement blends, advanced processing techniques such as statistical variance processing are needed and the presentation will detail the principles and effectiveness of this approach. Recent advances in spectral noise logging measurements with sensitive hydrophones will be discussed, these tools reveal that flow behind casing and fluid migration can be interpreted, which is complementary to acoustic and ultrasonic cement evaluation tools.