



Maximizing recovery in Brown Field Reservoirs through the Application of multidetector Pulsed Neutron Logging: A Comprehensive Review and Case Studies in Brown Field Management of Ankleshwar Asset

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Abstract:

This paper presents special cases for maximizing the hydrocarbon gain with an approach based on standalone integrated formation fluid identification using multidetector pulsed neutron tool. Cased-hole PNL is best suitable technology logs in absence of basic logs. Pulsed-neutron tool with at least three detectors) can provide three-phase formation fluid analysis in cased wells provide clear idea of formation fluid, hydrocarbon quantification, porosity calculation and lithology identification.

Recent exploration and development of more complex reservoirs require three-phase analysis (i.e., oil, water, and gas are all present in the reservoir). This requirement has led to the development of true gas saturation measurements in addition to the traditional water and oil saturation measurements. Previously, gas saturation was determined only by inference: If the sum of oil and water saturation was less than 100%, the difference was considered gas. All three saturation measurements can be made with a single instrument, providing a powerful set of measurements that can be used in petrophysical or well diagnostic problem.

Introduction:

Pulsed Neutron Technology, such as Reservoir Monitoring Tool (RMT™) can be utilized to evaluate older wells in brown fields. In addition to remaining hydrocarbon saturation, porosity and shale volume can also be derived when basic open-hole logs are not available. In the Mature Fields of Ankleshwar asset (ONGC) the oil and gas production has remarkably reduced. Moreover, Pulsed Neutron log is also very useful for identification of bypassed/residual oil from very high water cut or going to be abandoned wells. RMT was planned in infill well post drill to determine hydrocarbon saturation in absence of open hole logs. Based on PNL results well perforated and now well is producing good amount of hydrocarbon.

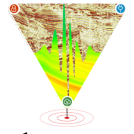
The fields within Ankleshwar Asset are characterized by their advanced age, resulting in a significant decline in oil and gas production. Over the past four years, there have been no contributions from exploratory wells. A recent study report has indicated that nearly half of the oil to be extracted within the next 40 years will come from already identified accumulations. This highlights the importance of focusing on the existing portfolio of assets and improving efficiency in oil field management. It is imperative to maximize the utilization of resources while minimizing investment. To identify potential opportunities for improvement, Ankleshwar Logging Services has taken the initiative to conduct a diagnostic review of existing wells. These wells have been categorized into three groups:

- Healthy Wells: These wells exhibit high and stable flow rates.
- Sick Wells: These wells experience unstable and variable flow rates.
- Comatose Wells: These wells demonstrate low and stable flow rates.

Extensive reviews have been conducted on the second category of wells, particularly in the Gandhar, Ankleshwar, and Jambusar fields. This comprehensive evaluation aims to identify strategies for enhancing the performance of these wells.

In absence of basic logs, RMT-3D was acquired in the few wells. Recorded sigma up/down pass at 4 meter per minute and 3 CO up passes at 1 mpm to quantify the leftover hydrocarbon and SAT-G measurement helped in identifying gas in the formation. Volume calculation of shale and porosity estimation has been done using standalone multidetector pulsed-neutron tool. For porosity RIN-RNF used for porosity calculation. Sigma & gamma ray used for shale volume calculation.

PNL logging in Ankleshwar Asset has been conducted since 2009. Upon revisiting old wells, it was realized that PNL (Reservoir Monitoring Tool) logs are highly



valuable in identifying bypassed or residual oil in wells with very high water cut or those on the verge of abandonment. By strategically planning CO/SIGMA logging in these old wells and employing advanced processing techniques, we achieved a significant gain of 289.84 TPD of oil and 6.4 MMSCFD of gas during the period of 2020-2021. This remarkable increase in production was attributed to the application of CO/SIGMA logging. Our services continue to focus on enhancing hydrocarbon recovery from these aging wells. In the year 2020-2021 alone, we generated a profit of Rs. 1,440,388,818.40/- through the production of hydrocarbons facilitated by CO/SIGMA logging. As for the current year 2021-2022, up until November 2021, we have already achieved a gain of 96 TPD of oil and 1.225 MMSCFD of gas.

Well Selection criteria:

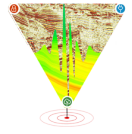
To ensure the successful execution of an RMT job, specific fundamental criteria must be fulfilled. The selection of the logging program and tool operation mode should be determined in advance, taking into consideration the prevailing circumstances and logging objectives. In the case of a freshwater regime, employing the sigma mode would not be beneficial; thus, it becomes necessary to utilize either the inelastic or the C/O mode. However, it is important to acknowledge the limitations associated with the C/O mode and bear them in mind when embarking on a meaningful job:

- **Porosity:** The selection of a well for C/O mode logging is significantly influenced by porosity. This is because the RMT tool, being a radioactive instrument, exhibits statistical variations in its measurements, much like other tools of its kind. When studying formations with low porosity, the signal strength tends to be weak, resulting in greater variations. This relationship can be visually explained using the Fan Chart, as depicted in Figure 7. The x-axis represents porosity, while the y-axis represents the C/O ratio. The blue curves correspond to limestone, while the red curves represent sandstone. The bottommost curve corresponds to 100% water saturation, and the topmost curve corresponds to 100% oil saturation.

Consider two scenarios: one with a porosity of 30 pu and another with a porosity of 10 pu. In the case of 30 pu, a slight variation in the C/O ratio (from point "a" to point "b") results in an error of approximately 7% in saturation estimation. However, if the porosity is 10 pu, the same variation in the C/O ratio leads to a significant error of 20% in So (oil saturation) calculation. Consequently, maintaining a porosity

level higher than 15 pu yields superior data quality and ensures reliable So readings.

- **Hole condition:** The depth of investigation of the tool in inelastic mode typically ranges from 6 to 8 inches. Therefore, if the target sand formation is collapsed or damaged, it will be positioned too far away from the source and detectors, making it challenging for the tool to receive data from the formation. Consequently, it becomes crucial to examine the open hole caliper within the desired sand intervals. In cases where caving and rough hole conditions are present, the collected data is inevitably affected, making it advisable to refrain from planning RMT recordings.
- **Quality of the cement:** The quality of cement behind the casing is another crucial factor to consider. In instances of poor cement bonding, the annulus tends to be filled with water or mud. When data is acquired, a significant contribution will come from this fluid, potentially leading to a pessimistic So (oil saturation) calculation. Conversely, if the annulus is filled with oil seeping from the underlying sands, it will yield unrealistically high So values. Therefore, in order to have confidence in the interpreted results, it is essential to ensure a good cement bond in the zone of interest.
- **Shut-in time before running PNL tool:** As mentioned earlier, the depth of investigation in C/O mode is limited, making the data susceptible to any changes in the immediate vicinity of the wellbore. When running RMT after well killing, with the objective of estimating the remaining hydrocarbon in a producing sand, it becomes crucial to allow the well sufficient time to stabilize (potentially 2-3 days). During the process of killing the well, the well fluid displaces the formation fluid near the wellbore. If RMT is lowered without allowing the formation fluid to return, the measured data will not accurately represent the signal from the actual formation fluid. Therefore, it is essential to exercise patience and ensure that the formation fluid has properly returned before conducting RMT, in order to obtain representative and reliable measurements.
- **Calibration:** When selecting the logging interval, it is crucial to include a water-bearing section and a shale section either below or above the target sand. The presence of a known water-bearing sand provides valuable information during the processing phase. It allows for calibration of the results, ensuring that the computed hydrocarbon saturation in the known water-bearing sand is 0%. By establishing this baseline within a zone of known water saturation, the



hydrocarbon saturations in other sands can be closely approximated to their true values. Thus, by matching the processed results in the zone with known water saturation, we can achieve more accurate estimations of hydrocarbon saturations in the other sands.

Hence, the careful selection of a well for a PNL job is crucial to obtain accurate and meaningful results from the interpretation. Thorough job planning, extensive discussions, and careful deliberation are necessary to determine the objective of running the tool. The logging mode is chosen based on the logging objective and the salinity of the formation water. To achieve optimal outcomes, it is advisable to form a team comprising individuals from operations, interpretation, geology, and production monitoring. This multidisciplinary team will collaborate to plan and execute the job effectively.

Tool theory:

In cased hole applications, Pulsed Neutron Logging (PNL) is a vital tool for evaluating formations through casing. When dealing with freshwater or unknown salinity conditions, carbon/oxygen (C/O) logging is particularly useful in determining the presence and saturation of water and oil behind the casing. The Ankleshwar fields, characterized by a relatively fresh salinity level of 8k ppm, extensively utilizes C/O logging for reservoir surveillance activities. The PNL tool operates on the concept of induced gamma ray spectrometry, where high-energy neutrons are directed into the formation. These neutrons interact with the formation in different ways:

- Inelastic Collisions (10us): In the first tens of microseconds, high-energy inelastic collisions occur, leading to the emission of gamma rays. The elements primarily contributing to inelastic spectra include C, O, Ca, Si, Fe, S, and Mg. These spectra are important for carbon/oxygen measurement but not relevant in capture logging.
- Elastic Collision & Absorption: From around 1000us onwards, neutron energy is gradually reduced through elastic collisions, until it is absorbed and emits a gamma ray. The elements predominantly contributing to capture spectra are H, Cl, Ca, Si, Fe, S, Ti, and Gd.
- Activation: Some instabilities created by neutron collisions may take seconds, minutes, or longer to return to normal. Gamma rays emitted during this period are not utilized in capture logging but hold significance in oxygen activation water movement logs or silicon activation gravel pack logs.

PNL operating procedure:

PNL tool is being run under shut-in condition and is avoided to take against perforated zone. In most common cases, it shows total sweep against perforated and previously tested zone due to water ingress into the formation. In general, the tool has been run in 7” & 5.5” casing. However, based on the Well completion design, it can be run in dual casing (Casing plus tubing. The detail of the logging procedure for acquiring the PNL log in the field is mentioned in Table 1.

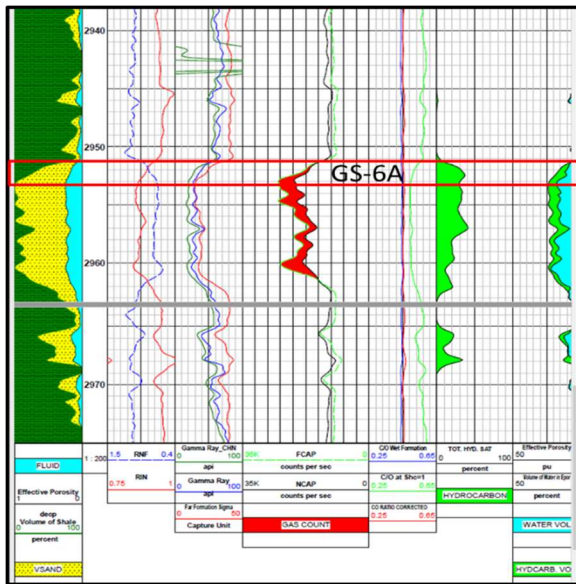
Logging type (Sigma, C/O)	Pass No.	Direction	Logging speed
Sigma	1 & 2	Up/Down	1200ft/hr
C/O	1	Up	1.0 ft/min to 3ft/min
C/O	2	Up	1.0 ft/min to 3ft/min
C/O	3	Up	1.0 ft/min to 3ft/min

Table 1: Logging speed for CO-SIGMA



Field Test Examples:

Example 1: The well G-XX is an inclined development L-profile well drilled down to 3025m with an objective of oil production from sand GS-6A within the Ankleshwar formation. Well was side tracked from 994m in 13 3/8” casing. Due to the hole problem casing has been lowered and recorded CHCN-GR log in the interval 1800-3000m, XMAC-GR log in the interval 1800-2984m and SBT-GR-CCL in the interval 2305-2988m. Finally CO log recorded for identifying the hydrocarbon bearing zone in the interval 2880-2975m. Based on the petrophysical analysis and CO log results, objective sand GS-6A, developed in the interval 2951.5-2961.5m found interesting from hydrocarbon point of view, and the interval 2951.5-2953.5m of this sand is recommended for testing. Accordingly the sand GS-6A was perforated in the interval 2951.5-2953.5m. On activation well flowed 21.6m³/d. Sample result: FW-nil, AW-17, TW-17 and Density-0.84



Case 1: CO result of G-XX

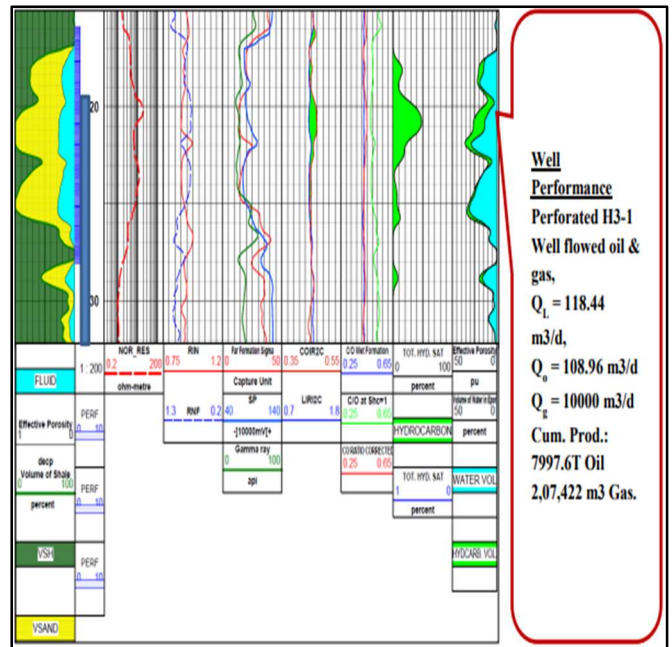
By planning of Pulse-Neutron in old wells during the year 2020-2021, there was gain of 362.3m³/d (289.84 TPD) of oil and 1,82,226.303 m³/d (6.45 MMSCFD) of gas. The process is still going on, for enhanced HC recovery from the old wells. During the year 2021-2022, from PN logging initial oil gain was nearly 191 TPD and gas gain was 1,33,530 m³/d. In current financial year till Q3 based on processed log data &

Interpretation of pulsed neutron logging & Ankleshwar asset has gained nearly 90TPD oil and 1.5MMSCFD of gas

Example 2:

The well A-XX was in abandonment after testing category. It was important to find any bypassed hydrocarbon saturation in such an old well and to take the production of HC. CO/SIGMA log was recorded against Lower to Upper Eocene pays. Porosity log as well as clean water bearing sand is not available in this section of the well.

Hence, porosity log of nearby well was provided along with water zone and shale intervals for processing of CO/SIGMA log. Based on CO/SIGMA log interpretation, Sand H3-1 in the interval AA20.5-AA21.5m was tested conventionally and after activation it has produced oil & gas @ QL=118.44 m³/d, Q₀=108.96 m³/d, WC-8%, QG=10,000m³/d through 10mm bean. FTHP=40ksc. The same sand is producing as on date.

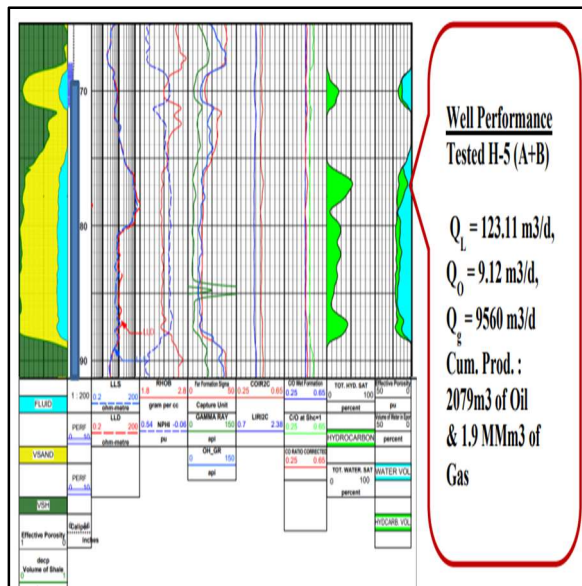


Case 2: CO result of A-XX



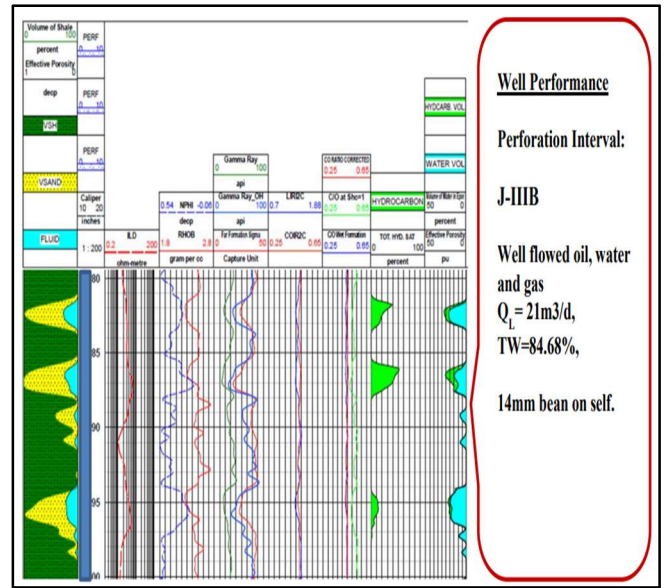
Example 3:

Initially, sand H-5C was perforated and it produced oil thru' 6mm bean with FTHP-126 kg/cm², Q_o: 41.4m³/d and Q_g-29,865m³/d. The cumulative production from this sand is 16,921 tons of oil & 14.98 MMm³ of gas. In the first work over job this pay was isolated by Bridge plug. Originally, the sands of H-8A, H-6A, H-5(A+B) were interpreted as HC bearing as per open-hole log. But, in this area nearby wells were tested and produced HC from these sands. These sands were water out in nearby wells. Hence, to know the bypassed HC saturation in this well CO/SIGMA log was recorded. CO/Sigma logs were recorded in Hazard section. Water bearing sand interval xx84-xx86m and shale intervals yy11.5-yy13m, yy67-yy68, yy93-yy94m was provided for calibration of CO/Sigma. Based on CO/SIGMA log interpretation, sand H-5(A+B) was tested and after activation it produced oil & gas @ QL=123.11 m³/d, Q_o=9.12 m³/d, WC=92.59%, (Sal=0.59 gpl), QG=9,560m³/d through 9mm bean. FTHP=45ksc.



Case3: CO processed output of G-XY

Example 4:



Case4: CO processed output of J-XX

Well J-XX was under abandonment category, PNL log taken before abandoning the well and based on PNL log interval decided to for perforation. Well flowed with oil, water & gas.

Conclusion:

PNL logging has proven to be a remarkably efficient, effective, cost-saving, and suitable logging tool for application in brownfields, both in the present and in the near future. By utilizing this tool to record logs in our fields and subsequently identifying bypassed hydrocarbons through log interpretation, we are driving innovation and making substantial gains. This approach can be regarded as a global standard in the developed areas of the oil field industry. Overall, this technology plays a vital role in brown field management. by providing leftover hydrocarbon saturation and insights necessary to optimize production, detect potential problems, and make informed decisions. It helps extend the economic life of mature reservoirs, maximize hydrocarbon recovery.

However, before making any decisions based on PNL data, it is essential to have a thorough understanding of the tool and its uncertainties specific to the field. Proper planning of PNL data acquisition, considering factors such as infill wells, integration of sigma and



borehole density logs with C/O measurements, and integrating PNL and PLT data for sweep analysis over time, has significantly contributed to the reliability C/O interpretation before perforation decisions are made. Additionally, analyzing production results following perforations guided by PNL data has played a vital role in maximizing field recoveries or gaining insights into sweep efficiency.

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