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PULSED NEUTRON ANALYSIS EXTENDS MATURE FIELD WELL WITH INCREASED OIL PRODUCTION

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ABSTRACT

The Sanga-Sanga region, Indonesia has several mature fields which have many wells without open-hole logs. The goal is to determine if these wells can be reactivated or improved performance. A pulsed neutron log was used to identify the remaining hydrocarbon potential by zone. Recompletion resulted in peak oil production of 700 BOPD with lower water cut.

The production data in the target well hinted at water encroachment or potential commingled production. The target well had cumulative oil production of 388 MBO through 1987 with subsequent deterioration to 12 BOPD on sucker rod pump today. Correlation with nearby wells shows the deeper sand has produced a cumulative of 65 MBO, with latest production of 36 BOPD and 51% WC. It was not clear whether the high-water cut is due to oil depletion in one or both sands.

The pulsed neutron logs with carbon oxygen ratio (C/O) and sigma measurements were acquired to determine the current oil saturation over each zone to design the recompletion strategy. C/O provides saturation independent of formation water resistivity whereas sigma is used for reservoir characterization (shale volume and porosity) due to unavailable open hole data. The C/O is the main source for saturation computation due to the low formation water salinity (3,000 – 3,500 ppm) of the reservoir. The target interval is correlated to a nearby offset well with open hole logs to constraint the porosity and shale volume calculation for saturation computation.

The pulsed neutron calculated 40-50% oil saturation and the well was successfully recompleted, with initial production up to 700 BOPD and stable production near 100 BOPD with a low water cut. Good well correlation is critical to ensure that the porosity is reliable and identify any water zones for reference to reduce uncertainty in the C/O based oil saturation.

This case study supports that old wells without open hole data can be reactivated by integration of historical well completion and production data and cased hole pulsed neutron data which is correlated to offset wells.

* **Halliburton**
** **Pertamina**

BACKGROUND OF STUDY

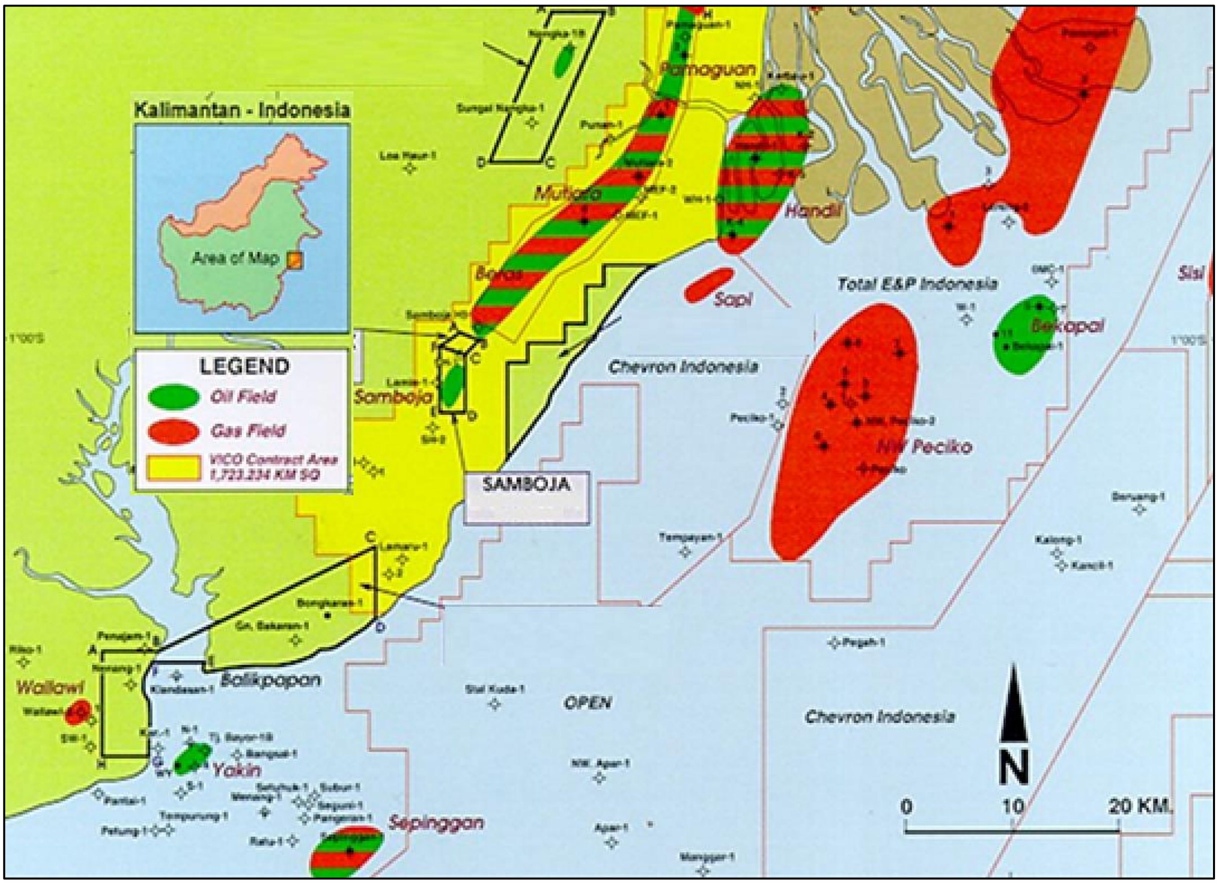

Figure 1 - Location of study area (JPT Dec 31st, 2013).

As a part of energy stability policy for Indonesia, the Ministry of Energy and Resources aim to increase the oil and gas production in 2030 to 1-million-barrel equivalent per day (BOEPD), where Indonesia has declining production since 2012, with 2022 production around 640,000 BOPD. Part of plan is to do more exploration (increasing proven reserves), and maximizing oil production through work-over, bypassed pay, and stimulation (I/EOR).

Sanga-Sanga field is located at East Kalimantan province, on the onshore of Mahakam delta, Indonesia. General structural geology across this area is the Samarinda Anticlinorium, with a series of anticline trap mechanisms that are prolific reservoirs in this region. The trapping mechanism is characterized by four-way dip closure or two-way structural / stratigraphic traps (Journal of Petroleum Technology, Dec 31, 2013).

With more than 50 years of production across multiple fields as shown in Figure 1, there are more than 400 wells, with different wellbore completions (single, dual, monobore, etc.). The study area is located at mature Samboja field, located South-West of the Mahakam delta. A thorough investigation of the well history documents revealed that there is potential bypassed pay in some sands in the well.

CHALLENGE DESCRIPTION

The focused well in this study is well-A where the information about this well was taken from archived well history (Figure 2). The first test was done at A-4 sand in February 1929 and the initial production was close to 1,000 BOPD. Total cumulative of more than 11,000 barrels of oil has been produced from this sand.

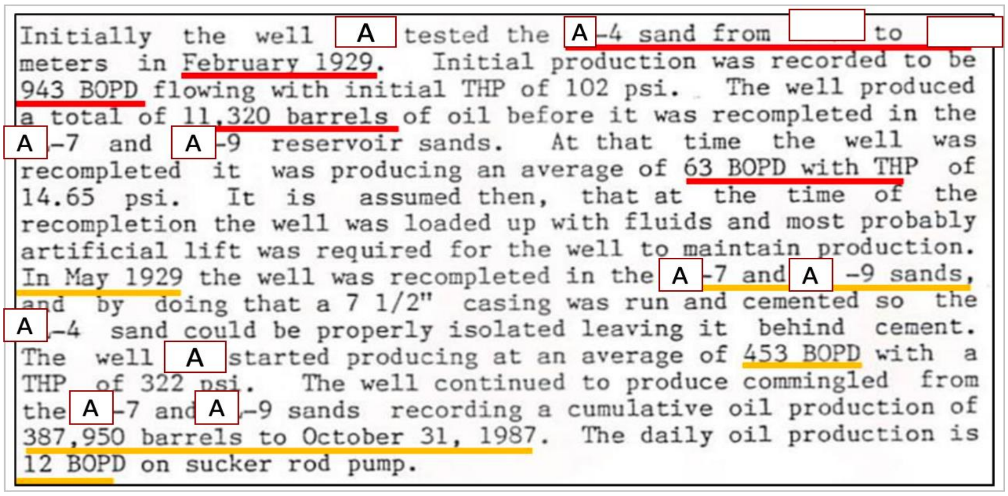
Initially the well A tested the A-4 sand from to meters in February 1929. Initial production was recorded to be 943 BOPD flowing with initial THP of 102 psi. The well produced a total of 11,320 barrels of oil before it was recompleted in the A-7 and A-9 reservoir sands. At that time the well was recompleted it was producing an average of 63 BOPD with THP of 14.65 psi. It is assumed then, that at the time of the recompletion the well was loaded up with fluids and most probably artificial lift was required for the well to maintain production. In May 1929 the well was recompleted in the A-7 and A -9 sands, and by doing that a 7 1/2" casing was run and cemented so the A-4 sand could be properly isolated leaving it behind cement. The well A started producing at an average of 453 BOPD with a THP of 322 psi. The well continued to produce commingled from the A-7 and A-9 sands recording a cumulative oil production of 387,950 barrels to October 31, 1987. The daily oil production is 12 BOPD on sucker rod pump.

Figure 2 - Well history details on production of different Sand intervals.

Subsequently, the A-7 and A-9 was recompleted together and produced around 60 BOPD initially. It was assumed formation damage from drilling fluid and artificial lift was used to successfully improve the production to 450 BOPD. The well continue to be produced commingled with a cumulative close to 400 MMBO as of 1987, with 12 BOPD as last daily rate using pump.

It is believed that the commingled production causes the high-water outflow, therefore a pulsed neutron log was deployed to understand the remaining oil saturation across A-7 and A-9, to evaluate water production and any bypassed pay. The other challenge is to evaluate the well without any open hole data available at the well.

PULSED NEUTRON APPLICATION

Pulsed neutron tools have been used in mature fields to evaluate reservoir condition through casing. Pulsed neutron tools emit high energy neutrons that penetrate through the casing and into the formation. The neutron particles slow down by bouncing off atoms (inelastic interactions) until they are finally captured. Each interaction releases a unique gamma ray which corresponds to the atom, the element. The composite energy spectrum from these gamma ray would correspond to the formation characteristics, such as mineralogy and fluid composition, which then can be processed to estimate the hydrocarbon saturation of the reservoir (Wijaya and Bagir, 2018)

TYPICAL Σ VALUES

MINERAL/FLUID	Σ VALUE	MINERAL/FLUID	Σ VALUE
SANDSTONE	4.6	SALT WATER (240 kppm NaCl)	118
LIMESTONE	7.5	OIL	18.2-22 **
DOLOMITE	4.7	GAS	UP TO 14 *
ANHYDRITE	12.6	QUARTZ	4.6
GYPSUM	18.6	CHALK	7.5
FRESH WATER	22	SHALE	20-50
SALT WATER (100 KPPM NaCl)	59	HALITE	761

* THE Σ VALUE IS DEPENDS UPON RESERVOIR PRESSURE, TEMPERATURE, GAS GRAVITY AND CONDENSATE RATIO.

** THE Σ VALUE DEPENDS UPON THE GAS OIL RATIO (GOR).

THE Σ VALUE FOR THE COMMON MINERALS IS SHOWN FOR PURE MATRIX. THE VALUE WILL VARY IN REALITY DEPENDING ON THE FORMATION CONDITION, i.e. TRACE IMPURITIES, CONNATE WATER SALINITY, ETC.

Figure 3 - Sigma values for common minerals, rocks, and fluids (Wijaya, et al., 2020)

There are two main ways to evaluate oil saturation in a reservoir through casing, capture/sigma, and inelastic/CO measurement. Particularly in Indonesia, and most of South-East Asia, the latter (CO) is the recommended method as the formation water salinity is rather fresh, therefore the sigma measurement would be ineffective to measure oil presence in reservoir due to the low contrast of oil sigma to freshwater sigma value (see Figure 3).

Although sigma cannot be used to evaluate the oil saturation, sigma data is useful to estimate formation shale volume and porosity. In the study case, the sigma data is used to estimate the shale volume and porosity due to unavailability of open hole data across target interval.

DATA QUALITY AND VSHALE-POROSITY CALIBRATION

Data Quality

There are two sigma passes at 15fpm and 3 CO passes at 3fpm acquired in this well. The sigma and CO data shows excellent data quality in terms of repeatability and spectrum analysis for CO as shown in Figure 4, 5, and 6 below. Curve mnemonics are available at the end.

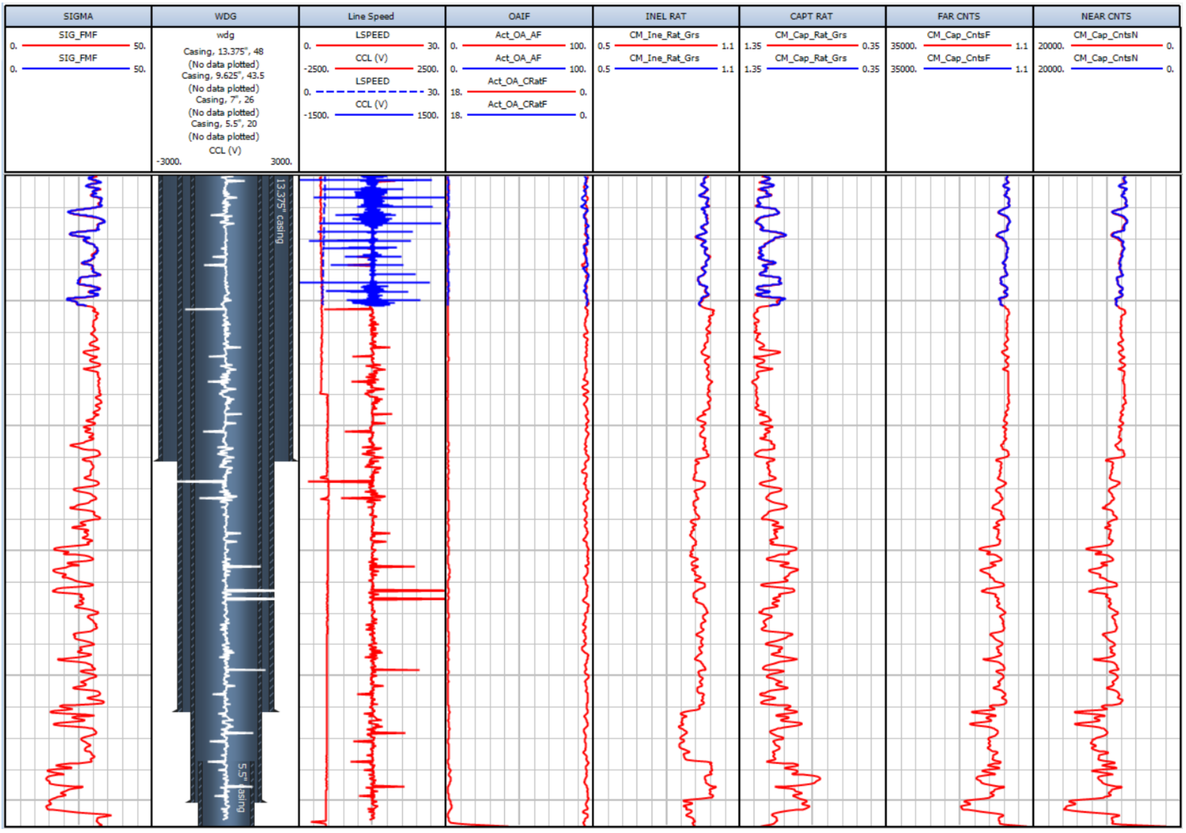

Figure 4 - Sigma data shows good repeatability between main (red) and repeat passes (blue).

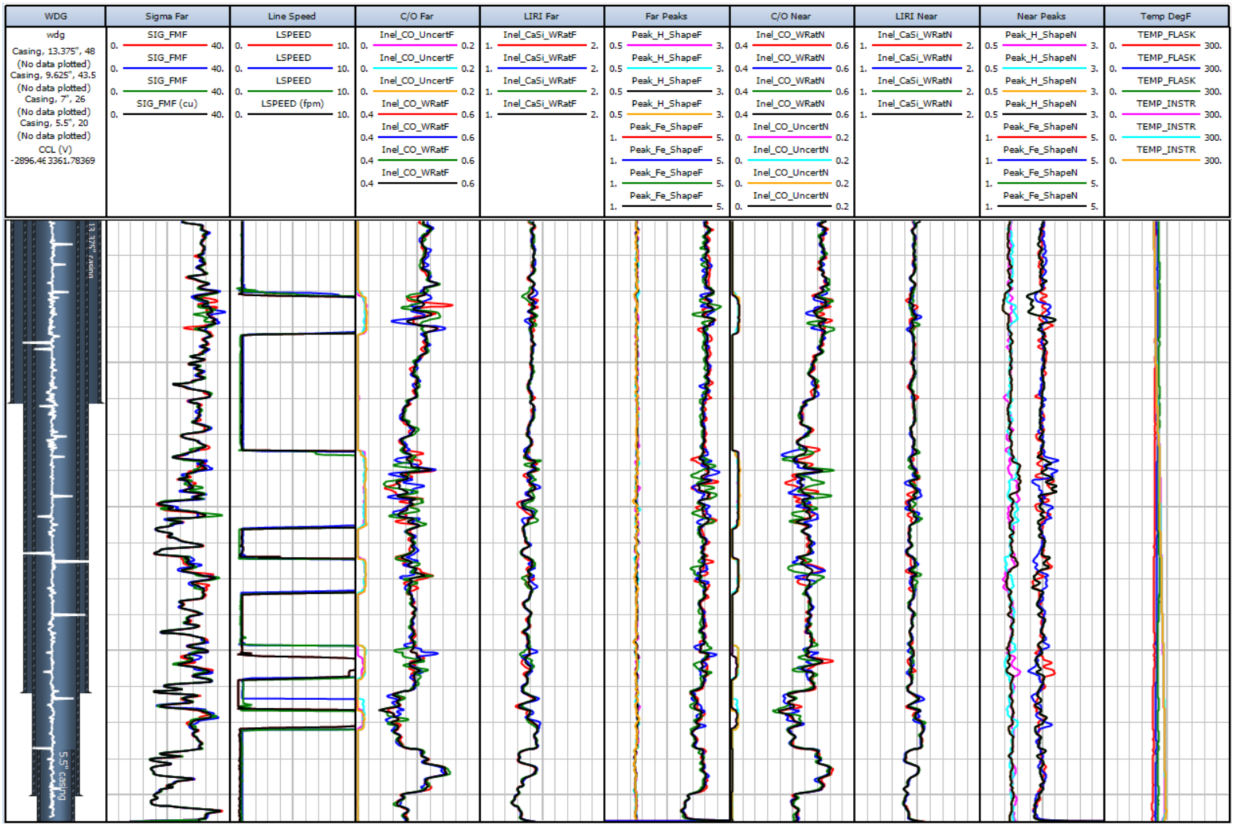

Figure 5 - CO data repeatability shows good repeatability between multiple passes.

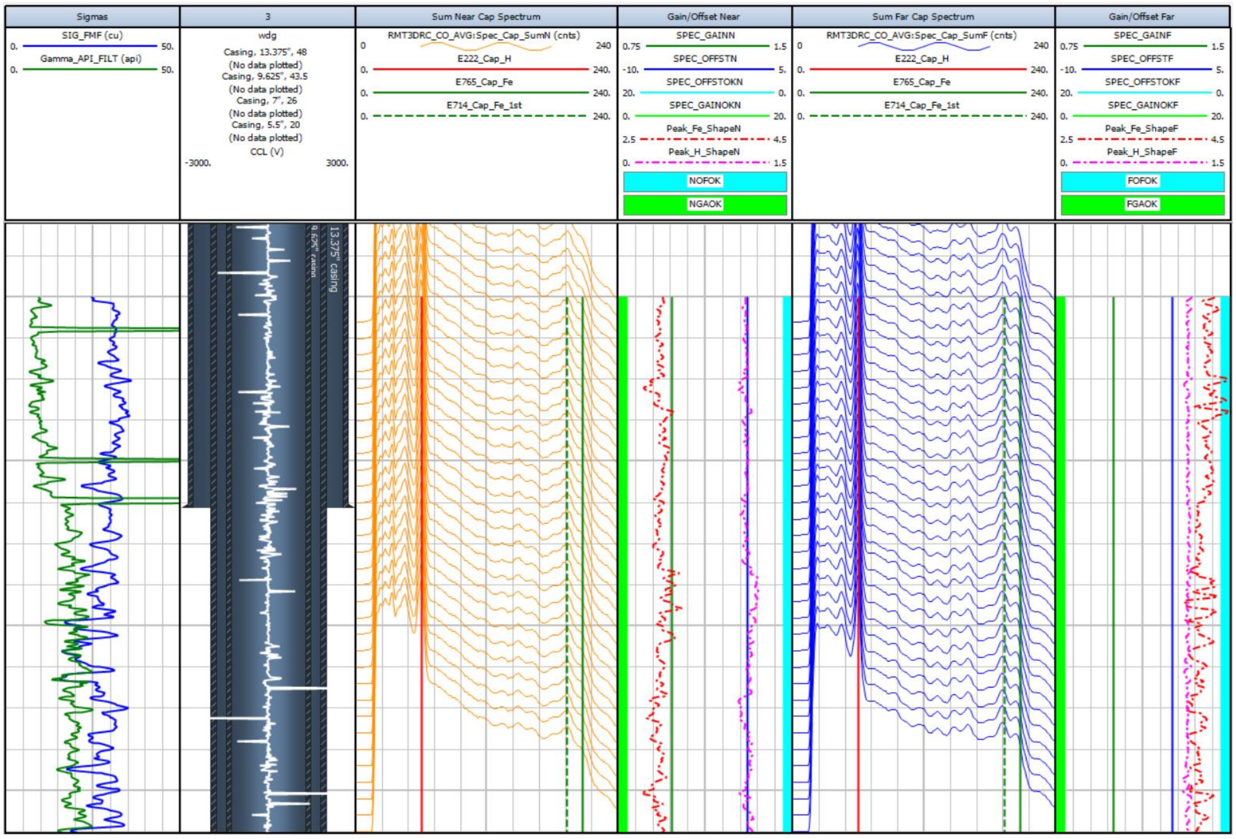

Figure 6 - CO data spectrum shows Hydrogen and Iron channel correctly in both detectors.

Volume of Shale and Porosity Calibration

Shale volume and porosity were calibrated using an offset well (Well-B) with open hole data across the target interval. The shale volume uses sigma formation from the far detector, because sigma formation can be a better representation of shale presence compared to gamma-ray, especially in an oil-bearing reservoir. The porosity is from cased hole near-far detector counts ratio, similar to neutron porosity in open hole environments.

For calibration, the well-B shale volume is used as reference to the calculated shale volume from well-A. Similarly, the neutron porosity from offset well is used as reference to the cased hole neutron porosity from studied well. The calibration uses multiple zones, based on the geological formations provided by the customer. Figure 7, cross-plots show the calibration between shale volume and porosity have a similar distribution. Furthermore, the overlay between cased hole shale volume and porosity bears similar resemblance to the offset well (track 7 and 8 in Figure 8).

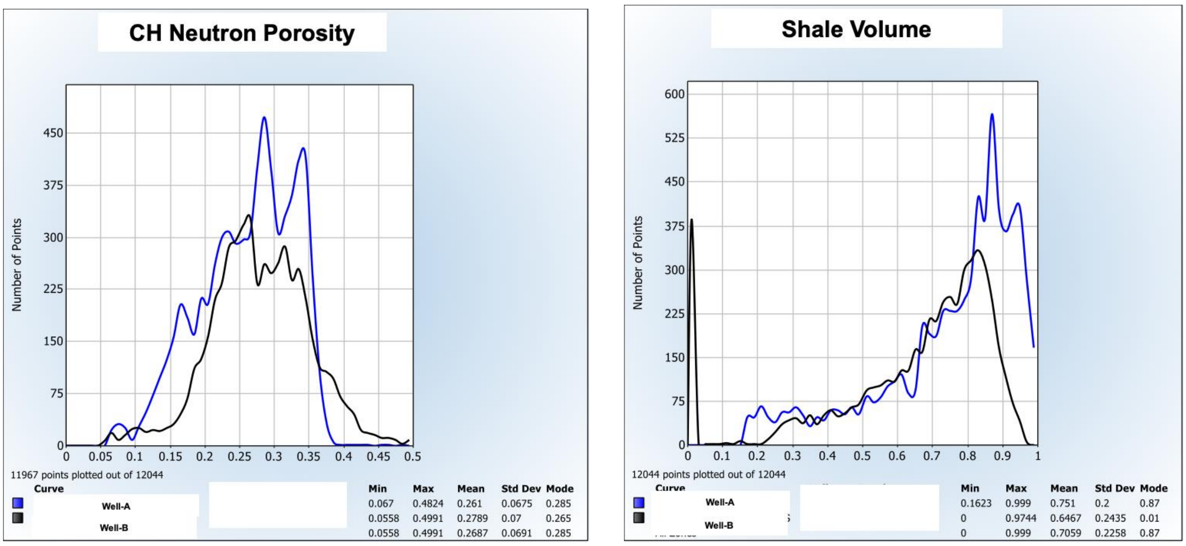

Figure 7 - CH neutron porosity and shale volume vs offset well.

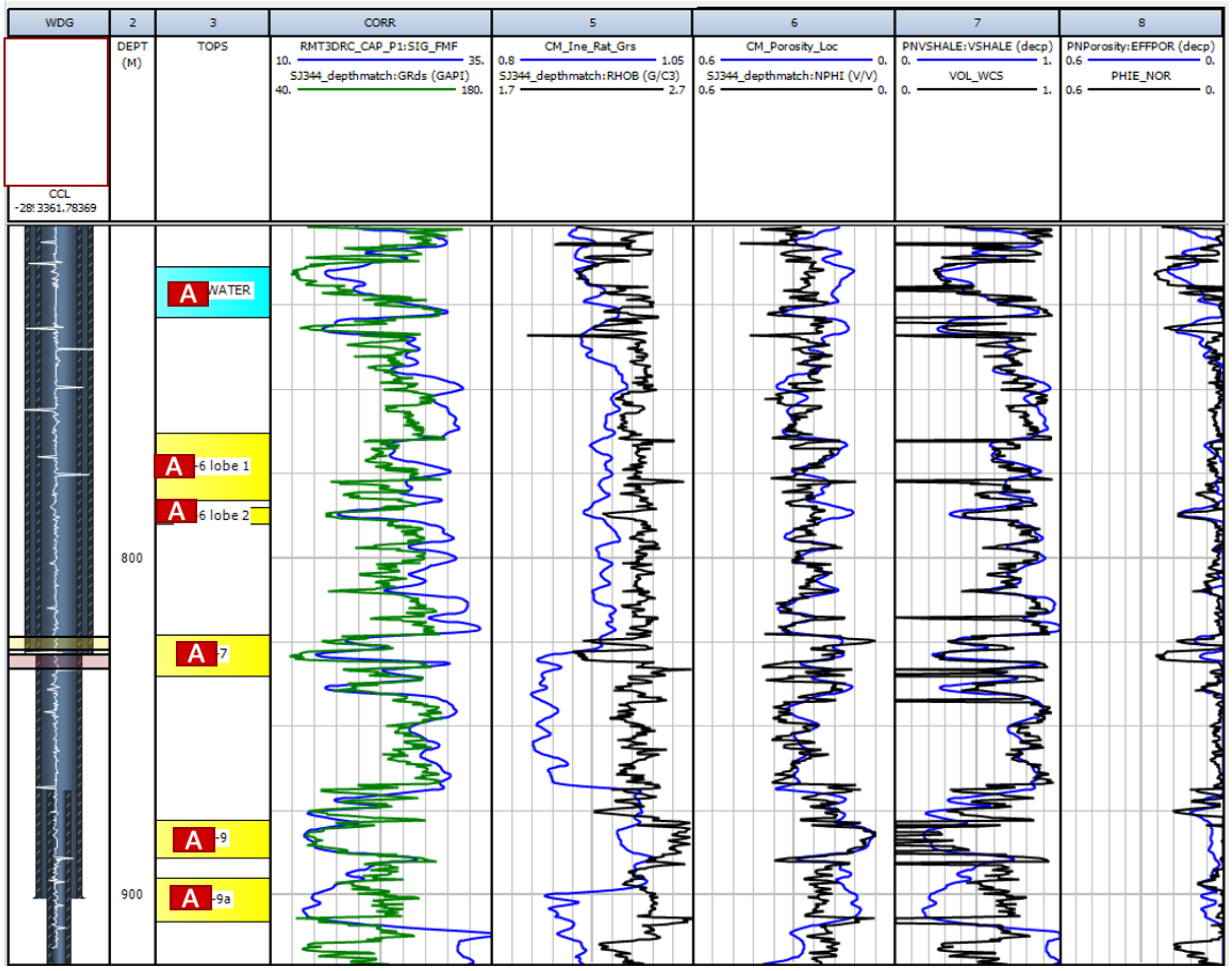

Figure 8 - CH shale volume and porosity calibration result to offset well.

Water-zone Reference

A water-bearing zone is used to validate the CO data, as a baseline to compute the remaining oil saturation across target intervals. There is no clean water-bearing zone near the target intervals, with the A-4 sand above a potential water zone. Since the target intervals (A-7 and

9) are in a different formation (and completion) than the A-4 sand, local knowledge from production e.g., zone that has been perforated and/or has been squeezed as reference was used to constrain the calibration over the target interval.

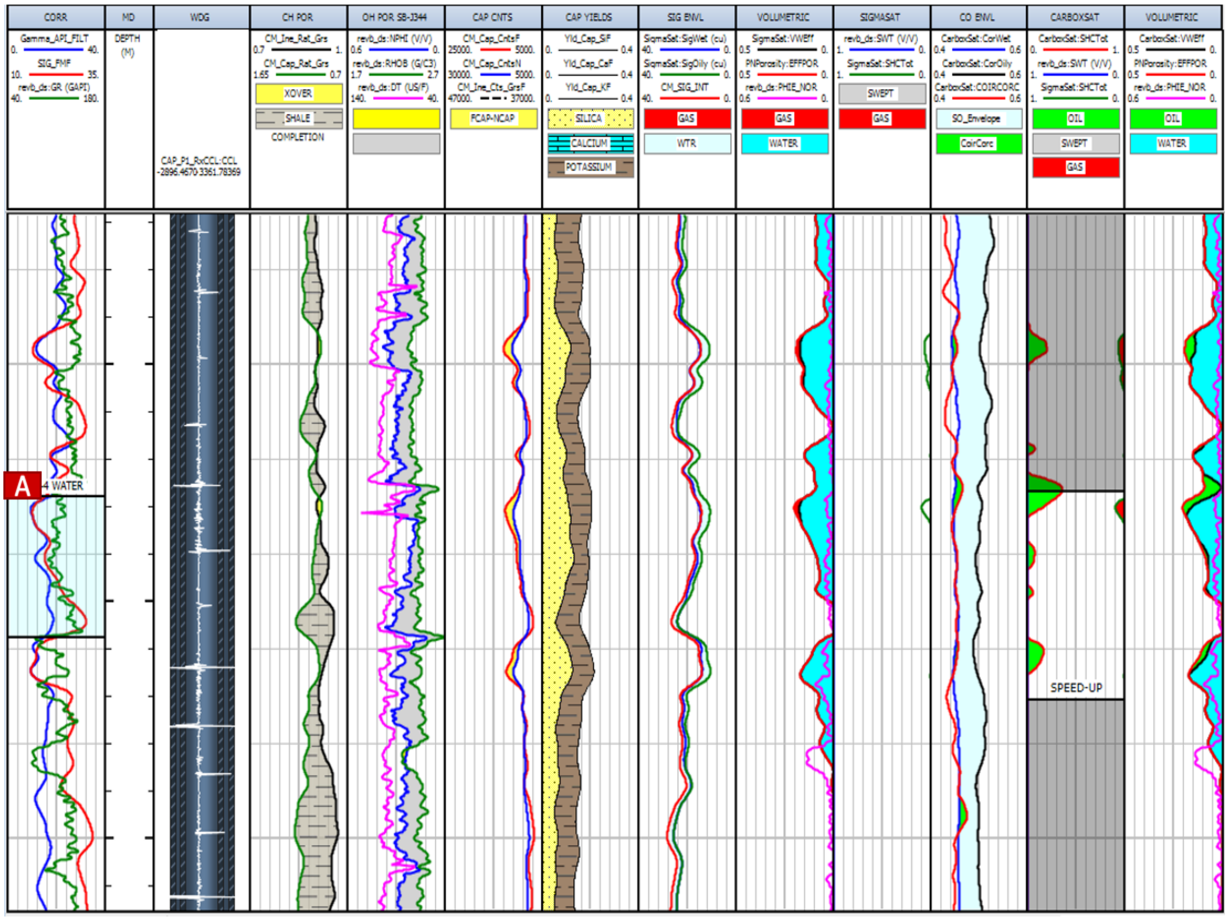

Figure 9 - Water zone reference

PROCESSING AND PRODUCTION RESULTS

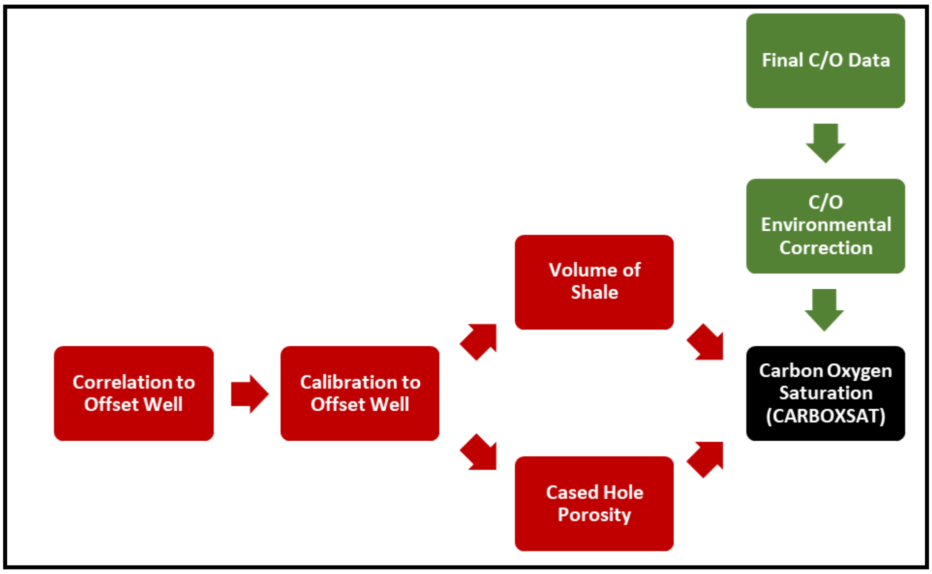

Figure 10 - Processing flowchart

Processing Result

Once calibrated, the results over the A-7 and A-9 target interval show some intervals with some remaining oil saturations (Figure 11) as follows:

A-6: shows around 15% remaining oil saturation, and believed to be predominantly water and residual oil and should not be considered as a potential zone for workover.

A-7: this sand has been opened and then squeezed, so the expected oil saturation is believed to be low as shown in the Figure 11, around 15% remaining oil saturation.

A-9, A-9a: both sands show high CO ratio with computed remaining oil saturation of 40-50%.

It is a challenging task to confirm if the computed oil saturation is real, or an effect from possible coals (lignite) which is common in this area, or a centralizer behind the tubular (any change of metal thickness increases the CO ratio), or matrix change (carbonate-rich rocks). Eventually, the decision to perforate these sections is supported by well history and local knowledge about depletion behaviour from nearby wells and geological understanding of the area.

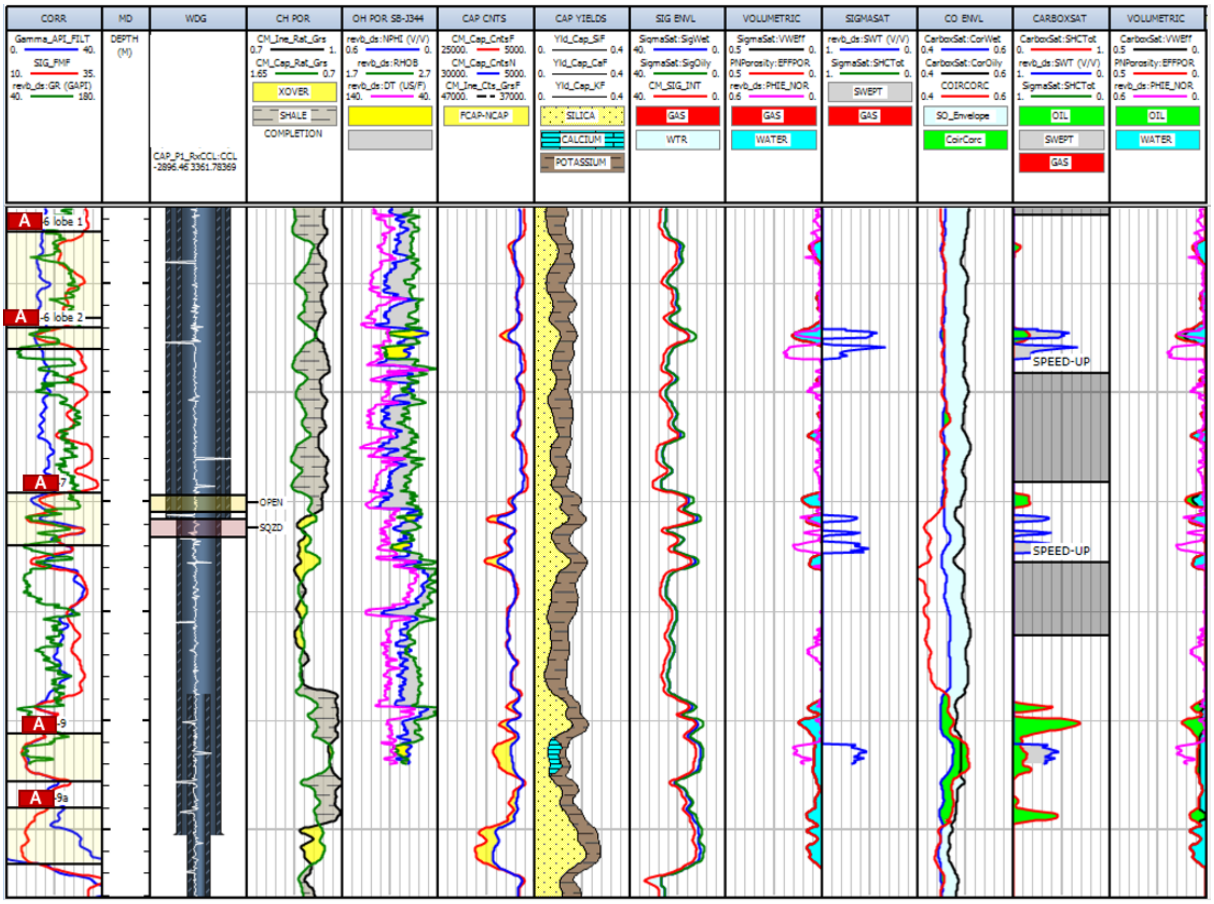

Figure 11 - CH saturation result across target interval.

Production Result

The decision was made to perforate and produce A-9 and A-9a together. The initial 4-hour test rate was 70% water cut with 40 BOPD, the 6-hour test gives 53% WC with 87 BOPD. Eventually, the 12 hours test produced 51% WC, and 246 BOPD. The initial production rate is up to 700 BOPD, and now stabilized at 100 BOPD after five months.

CONCLUSIONS AND FUTURE WORKS

The application of pulsed neutron to determine possible bypassed pay to optimize the production rate is well-known in the industry. In the absence of open-hole data, the use of sigma can be important to determine shale volume, and porosity, both are important inputs in calculating hydrocarbon saturation. In the studied area, it was shown that the integrated analysis of previous information from well history, local knowledge, offset well production, and robust calibration of shale volume and porosity can give a reasonable understanding of remaining oil saturation across unknown intervals. Pulsed neutron logging can be used to reduce the uncertainty in a mature field workover optimization strategy, where there is no open hole data to support the interpretation.

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CURVE MNEMONICS

SIG_FMF: Far Sigma Formation
CM_Sig_Int: Intrinsic Sigma Formation
LSPEED: Logging Speed
CCL: Casing Collar Locator
Act_OA_AF: Far Oxygen Activation
CM_Ine_Rat_Grs: Inelastic Ratio
CM_Cap_Rat_Grs: Capture Ratio
CM_Cap_CntsF/N: Far/Near Capture Counts
Inel_CO_UncertF/N: Far/Near CO Inelastic Uncertainty
Inel_CO_WRatF/N: Far/Near CO Inelastic Ratio

Inel_CaSi_WRatF/N: Far/Near Ca-Si Inelastic Ratio
Peak_H_ShapeF/N: Far/Near Peak for Hydrogen
Peak_Fe_ShapeF/N: Far/Near Peak for Iron
Yld_Cap_S/Ca/KF: Far Yield Capture Spectrum for Silica/Calcium/Potassium
Temp_Flask: Instrument Temperature
CorWet: CO Ratio at 100% Water
CorOily: CO Ratio at 100% Oil
COIRCORC: Corrected CO Ratio