Increasing Hydrocarbon Recovery By Improving Net-Pay Determination Using PNL In "B" Field

Ratnayu Sitaresmi, Danaparamita Kusumawardhani, Eko Prastio, Muhammad Taufiq Fathaddin, Suryo Prakoso

Abstract: In the effort of increasing oil recovery, the accuracy of hydrocarbon zone determination plays a very important role. Failure to properly predict the thickness of hydrocarbon present, poor decisions in the development plan are likely to be pursued. Therefore, this research aims to evaluate the formation of "B" Field, focusing on determining the thickness of hydrocarbon zone present and assessing the remaining/residual prospect of its saturation. Being a mature field with fully cased wellbores, an improved Cased-Hole logging method named a Pulse Neutron Logging (PNL) is used inside the tubing for this study. It is particularly beneficial for an old well where the change of depth of the Oil-Water Contact occurs, so that the perforation interval can be furtherly optimized. "B" Field initially predicted to produce 180 BOPD without PNL, is able to show increment in oil production prediction by 20 – 40% after its application, with a 220 BOPD boost. Furthermore, unlike the Conventional Neutron Log (CNL), PNL measures porosity by detecting Sigma and Carbon Oxygen Saturation instead of hydrogen index, which shows the ratio of the concentrated hydrogen (atoms/ cm^3) of rock to water. Therefore, this method is useful to avoid misinterpreting Shale as a high porous zone for having a high hydrogen index. It also aids to ascertain the ideal water between fresh and brine, capable of predicting the net-pay more accurately.

Index Terms: Pulse Neutron Logging, CarbonSat, SigmaSat, Cased Hole Logging, Net Pay, Porosity, Oil/Gas Production

1. INTRODUCTION

Neutron log is commonly used to distinguish porous formations and calculate its porosity. Conventional Neutron porosity measurement detects the presence of hydrogen by measuring the its index in rock formations, which is defined as its concentration ratio per cubic cm, (atm/cm^3), of rock to the content of formation water. Therefore, the more greater the hydrogen content found in the formation, the more porous a formation is read on the Conventional Neutron Log. This will reduce the accuracy of the prediction when Shale formation is encountered. This is because it contains a lot of hydrogen and therefore, it could be misinterpreted as containing high porosity.

Additionally, in a clean formation where the pores have been filled with oil or water, the Neutron log also detects the porosity in which is filled with fluid. Neutrons has no charge and interacts with other materials in two ways namely collision and absorption. The greatest energy loss occurs when it collides with another material consisting of same mass, such as, hydrogen nucleus (Khan, et al., 2016). Therefore, assuming a large decrement of neutron atoms returned is examined, it can be predicted that it also consists of high amount of water present in the formation.

This research aims to provide a formation assessment of "B" Field using a Pulse Netron Logging (PNL) tool. The "B" Field, which is located in the East-Java, Indonesia, and is mature with old wells that have been producing oil for a long time. A typical old wells would have been fully cased and completed. Therefore, this study utilizes PNL because it is currently the most commonly used technology for cased-hole suitable to be used for "B" Field (Amer, et al., 2018). The main purpose of using this advanced method is to improve the determination of the net-pay zone, to pursue the right development plan. Moreover, other than to increase the hydrocarbon recovery, PNL is also utilized to identify the new potential hydrocarbon zone.

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2 LITERATURE REVIEW

Pulse Neutron is a device to measure carbon content in oil and oxygen in water. It has the ability to run in both open and cased-hole environments, to provide the saturation, porosity, shale content, and mineralogy information of the well. Figure 1 below shows that when the water is encountered, this device indicates a high level of O atoms and low level of C atoms. Conversely, when this device captures hydrocarbons, then high C atoms and low O atoms will be shown. However, the ratio of Carbon to Oxygen presented for both water and hydrocarbons is likely to be influenced by water salinity.

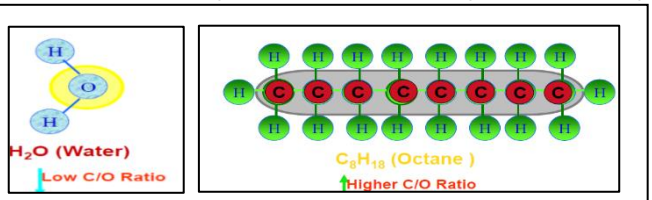


Fig.1 *Water Atom and Hydrocarbon Atom*

Therefore, the C/O is best to be specified only for oil.

The amount of energy fired by this tool from its accelerator source into the well is 14 MeV (Quinlan, et al., 2012). From each energy level emitted by Pulse Neutron Log, the ratio of several minerals and atoms i.e. C, O, Ca and Si is achieved. After obtaining the aforementioned minerals and atoms ratio, the saturation of oil is determined by calculating the ratio of C/O, also known as RMT C/O, and the ratio of Ca/Si, or so called LIRI and then comparing the porosity of the open-hole. Other than Carbon-Oxygen Saturation, PNL also detects the Sigma Saturation. This process involves the collision of fast neutrons that travels into the formation with another nucleus during which 0.025 eV is lost. This is called a thermal neutron. Sigma or capture cross-section is basically measures the ability of nucleus to capture a thermal neutron (Amer, et al., 2018). For instance, in a typical

formation where high amount of Chlorine is present, Sigma tends to show the highest capture cross section (Khan, et al., 2016). Therefore, with this Sigma process we can distinguish between salt water and oil, vapor and water, oil and vapor. The Vapor here consists of Methane, Carbondioxide, Nitrogren and Steam.

3 RESEARCH METHODOLOGY

The methodology used to conduct this study is as following;

1. Data collection

Data was collected from the "B" Field. The data is in the form of LAS, NTI, Open Hole Log data, Cased Hole Log, Well Diagram and several file history from the well.

2. Data Processing

After the sufficient data is acquired, the following data processing is to be done;

- Depth Match
  Depth match involves aligning or equalizing GR Open Hole data with GR Cased Hole data.
- Calibration of each Pass.
  Calibration aims to correct the initial data acquired to be representative of the well environment.
- Gain Stabilization
  In these processes all curves will be aligned to the Hydrogen Peak Window.
- Pulse Neutron Interpretation
  In this process, various information from Open Hole Data is to be entered into the system such as the Vshale, RhoOil, RhoGas, Litology, Bit Size, TPor and so on. On the final processing of PNL, there are three columns is to be created, namely Carboxsat, Sigmasat and Triplesat, which will show oil saturation, gas saturation and presence of oil and gas, respectively.
  To get Oil Saturation, you can also use a formula

$$S_{oil} = 1.53 * \frac{1-0.35\,\phi_T}{\phi_T} * \frac{\Delta\,C/O}{\Delta\,C/O + 0.27\rho_{hc}}$$

In the above calculation, total porosity and hydrocarbon density is necessary to be included to obtain the saturation of the oil. As for the C/O difference, the following Eq. (2) can be used to achieve the value.

$$\Delta\ C/O = C/O_{meas} - C/O_{wet} \quad (2)$$

Shown below in Figure 2 is the workflow diagram to achieve Relog for CO Data for Carboxsat.

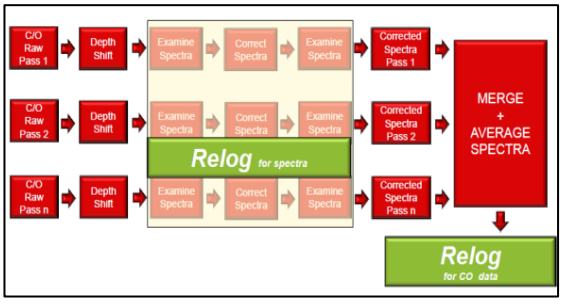


Fig. 2 *Carboxsat Flow Chart*

- Sigma (∑) (SigmaSat)
  In order to calculate for gas saturation, the formula below can be used;

$$\Sigma_{log} = \Sigma_{ma}(1-\Phi-V_{sh}) + \Sigma_w(S_w)(\Phi) + \Sigma_{sh}(V_{sh}) + \Sigma_{hc}(1-S_w)(\Phi) \quad (3)$$

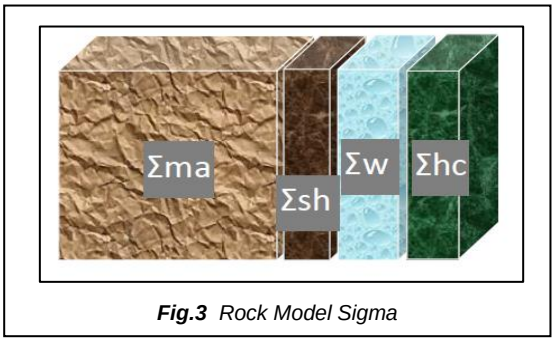


Fig.3 *Rock Model Sigma*

To obtain the result from Eq. (3), there are several parameters required. One of which is the parameters from open holes data; such as porosity and Vshale data. Another information that is necessary to calculate gas saturation with SigmaSat are Sigma water, Sigma shale, Sigma matrix and Sigma Hydrocarbon, which can be acquired from the following Table 1.

TABLE 1
SIGMA ROCK AND ESTIMATED FLUID

Lithology	Σ (Sigma)	Fluid	Σ (Sigma)
Sandstone	4.3	Gas	0-12
Dolomite	4.7	Oil	18-23
Calcite	7.1	Fresh Water	23-35
Anhydrite	12	Salt Water	35-60
Clay	28-44		

The illustration in Figure 4 shows a log response on SigmaSat and CarbonSat and its interpretation. It can be seen in the figure that both oil and fresh water will show almost the same reading and, hence, reduce the effectiveness of this method when analyzing the fresh water environment. Therefore, it is best to use SigmaSat when the formation has high salinity.

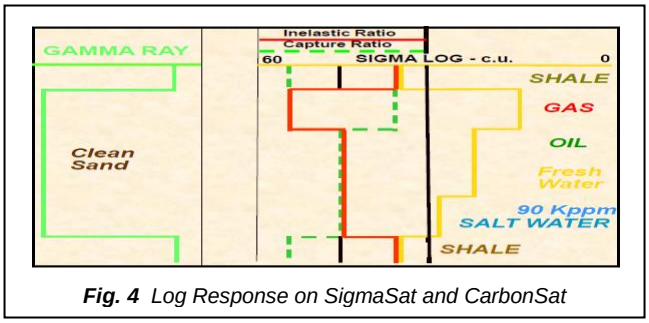


Fig. 4 *Log Response on SigmaSat and CarbonSat*

In this study, the PNL will combine Sigma Mode and C/O Mode to be a tool to evaluate gas and the potential for oil inside well X of "B" which is located in East Java.

The main objective of the Reservoir Monitoring Tool (RMTI) is to identify the remaining hydrocarbon potential in the prospect zone, inside the casing, in order to determine the reservoir pressure along with type of fluid before getting updated data reservoirs for evaluating candidates for workover.

- Information on Wells
  On the 28th of November 2014, The PNL (Sigma Mode and C/O Mode) have been applied to the selected well of "B" Field named X well. The PNL were run inside 4.5 "liner and on intervals 7650 to 7860 ft MD. As for the PNL Sigma mode were run on 7 "and 4.5" liners on intervals of 5600 to 7850 ft MD. But for processing only on intervals of 5640 to 6000 ft MD.
  Environmental Correction has been done for the PNL which includes :
  - Casing size
  - Casing thickness
  - Bit size
  - Lithology
  - Salinity of water inside the casing

  The SigmaSat Module is used to obtain Gas Saturation by calculating Sigma Intrinsic and Carboxsat Modules. As for the C/O ratio from PNL will be used to calculate the Oil Saturation.

4. RESULT AND DISCUSSION

Data Quality Analysis
All data goes through the RMTI Process Modeling for Stabilization Energy Gain windows and environmental correction, with the aim of minimizing the effects of wellbore and tools in the well that might affect the calculation. Before working on the RMTI data first through the stage, the data is prepared first and this is discussed in the sub-section below;

4.1 Interpretation Model
After going through the above process, data generated undergoes several stages of correction. This correction is used so as to minimize errors in reading the tool because there are too many disturbances in the well. In this interpretation there are two models, namely sigma and C/O. Sigma is used to search for gas and C/O the goal is to find oil.

4.2 SigmaSat Interpretation
Sigma Saturation Log (SigmaSat) is one of the interpretation modules for Pulse Neutron which is used to calculate Sigma Saturation. Figure 5 below shows the processing work-flow of Sigma Log to acquired sigma saturation reading.

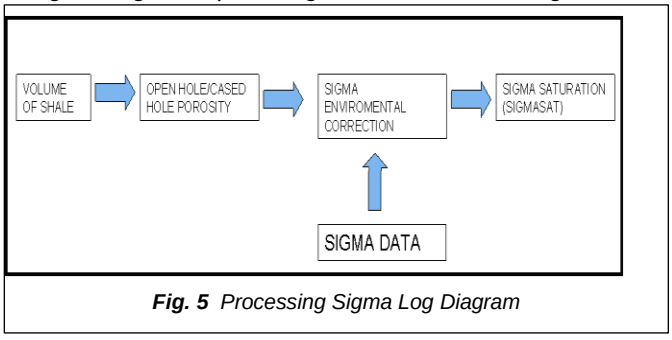


Fig. 5 *Processing Sigma Log Diagram*

In the Sigma Saturation Log detection, the parameter used will be as follow;

- ∑water = 32 Cu, for formation water salinity: 6 Kppm
- ∑gas = 3 Cu, adjusting to the temperature dan pressure.
- ∑shale = 12 Cu, adjusting to the sigma intrinsic value in shale zone
- ∑matrix = 8 Cu, adjusting to the sigma apparent matrix value in the clean water zone.

In this discussion, the author aims to explain the results of processing Sigma Saturation (SigmaSat) and Carbon Oxygen Saturation (CarboxSat) to detect gas saturation and oil saturation, respectively.

Interval 5700 – Top Logged
5640 - 5676 ft interval
Shown in Figure 6, The Gamma Ray Openhole and Casedhole is present in the track one. The permeable zones looks like the same. At this interval, a cross-over between RNF and RINC is seen because of the gas present both in the borehole and in the annulus.

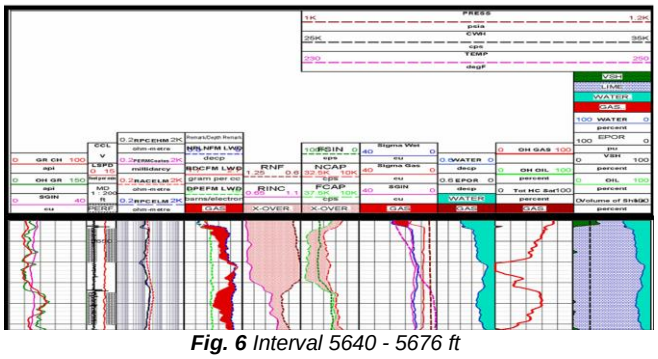


Fig. 6 *Interval 5640 - 5676 ft*

5676 - 5700 ft interval
Shown in Figure 7, The Gamma Ray Openhole and Casedhole is present in the track one. The permeable zones looks like the same shape. The smaller cross-over between RNF and RINC is predicted to be caused by the gas in the borehole and water in the annulus.

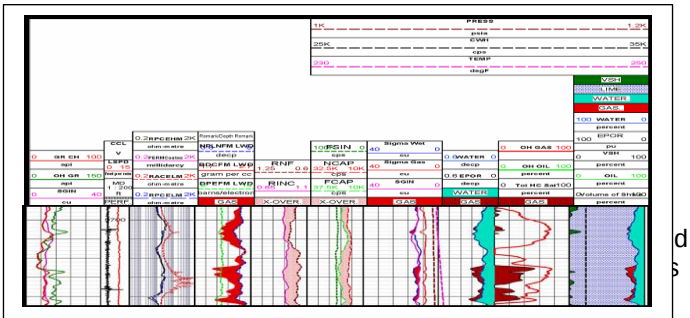
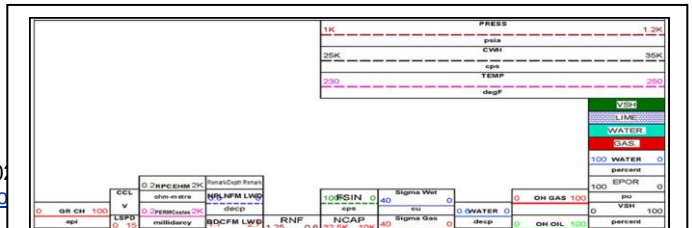


Fig 7. *Interval 5676 – 5700 ft*

looks like the same.SGIN values are observed around 10 Cu and wet Sigma is around 14 Cu, this makes the separation between SGIN and Sigma Wet and could be read as gas saturation. There is a cross-over between RNF and RINC where the water is present in the annulus and gas is present in the borehole. The effective porosity of the formation is around 13-25% with 1-5% of Vshale and gas saturation around 20 to 40%.



Interval 5750 - 5800 FT

Shown in Figure 9, The Gamma Ray Openhole and Casedhole is present in the track one. The permeable zones looks like the same. SGIN value is around 10 Cu and Sigma Wet is around 14 Cu, there is a separation between SGIN and Sigma Wet which indicates gas saturation. There is also a Cross Over between RNF and RINC because there is water encountered in the annulus and gas encountered in the borehole. The effective porosity at this interval is around 18-25% with 1% of Vshale and the gas saturation is around 60%.

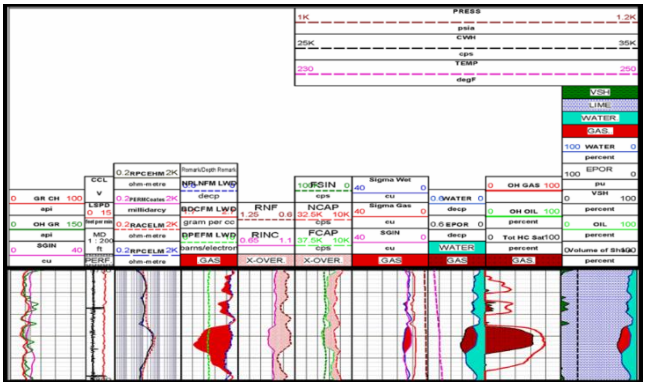
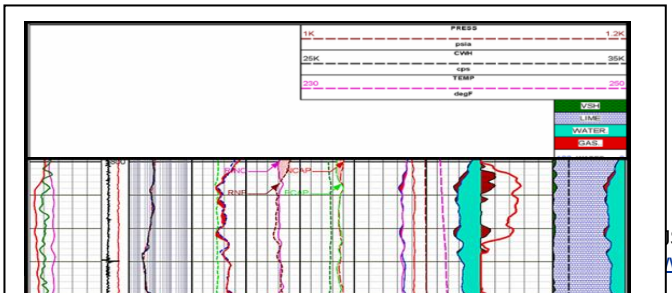


Fig 9. *Interval 5750 to 5800 ft*

5800 - 5825 ft interval

Shown in Figure 10, The Gamma Ray Openhole and Casedhole is present in the track one. The permeable zones looks like not the same. SGIN value is seen to be around 10 Cu and Sigma Wet is around 14 Cu. It is making a little separation between SGIN and Sigma Wet which will could be used to calculate Gas saturation. The cross-over between RNF and RINC is because of the presence of water in the Annulus and gas in the borehole. The effective porosity at the respective interval is around 15 to 30 % with 1 to 5% Vshale and gas saturation less than 20%.



4.3. Cabon Oxygen Interpretation

7674 - 7686 ft interval

Shown in Figure 11, The Gamma Ray Openhole and Casedhole is present in the track one. The permeable zones looks like not the same. As shown in the C/O Sat reading, the oil saturation can be determine and the results in 20 to 40% and the effective porosity is around 15 to 35 %. The gas water contact is present at this interval, predicted to be at 7700 ft.

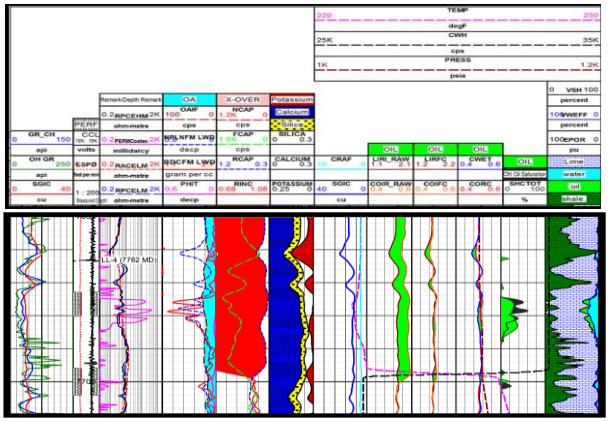


Fig. 11*. Interval 7674 to 7686 ft*

7764 - 7768 ft interval

Shown in Figure 12, The Gamma Ray Openhole and Casedhole is present in the track one. The permeable zones looks like not the same. In the track three shows that the C/O Sat reading can as well be used to determine oil saturation, which is predicted to be around 20% and the effective porosity of formation in this interval is around 18 to 25 %. It is predicted that water is already present in Borehole.

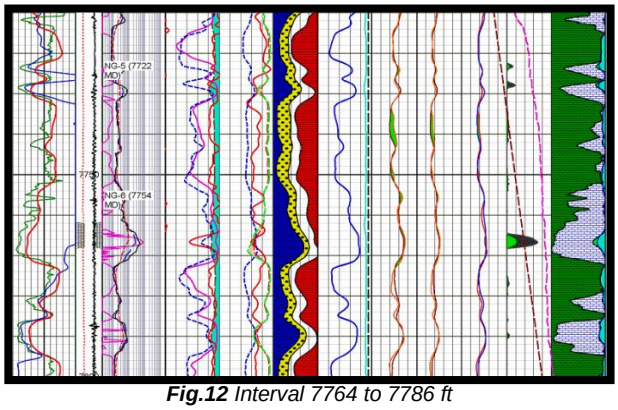


Fig.12 *Interval 7764 to 7786 ft*

he PNL, Cased Hole Logging - Sigma Saturation, it can be seen that there are several zones of the prospect of Hydrocarbons, where Residual Gas Saturation is located at the interval:

- Depth 5775 - 5788 ft, with Shale Volume value of 1%, Effective Porosity of 18-25 %, and Residual Gas Saturation of 60%.
- Depth 5724-5742 ft is gas zone with gas saturation and effective porosity around 13-25% with 1-5% Shale Volume, Effective Porosity is 13-25%, and Residual Gas Saturation is 20-40%.
- Depth 5800 - 5825 ft with 1-5% Shale Volume, Effective Porosity is 15-30%, and Residual Gas Saturation is less than 20%.
- From Cabon Oxygen Interpretation, Depth 7674 - 7686 ft interval Oil saturation is around 20 - 40% and effective porosity is around 15-35 %. Gas Water contact at 7700 ft.
- From Cabon Oxygen Interpretation, Depth 7764-7768 ft interval oil saturation is around 20% and effective porosity is around 18-25 %. Water in borehole.

2. Based on the qualitative interpretation of the PNL Cased Hole Logging - Carbon Oxygen Saturation, it can be seen that several zones that are still zones of the Hydrocarbon Prospect, where Residual Hydrocarbon Saturation is located at the interval:
   - Depth 7764-7768 ft, with an Effective Porosity around 18-25% and Residual Hydrocarbon Saturation at 20%.
   - Depth 7674-7686 ft with an Effective Porosity is 15-35% and Residual Hydrocarbon Saturation is 20-40%.
3. Gas-Water Contact can be detected through a device which is located at 7700 ft.
4. The current of oil production is 180 BOPD. After the net pay determination is improved, the oil production is increased by 20-40%. Where the estimated oil production is able to reach 220 BOPD.
5. PNL is advantageous to distinguish between fresh and brine water which will make the net-pay prediction more accurate.

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