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Validation of C/O Log Interpretation using Fractional Flow Curve on Workover Plan of Offshore Oil Well

Roni Wibowo[1], Yohanes Novian Aribowo[*1] and Ferdinandus Klea Latuan[1]

[1]Petroleum Engineering, UPN "Veteran" Yogyakarta
* Email: novian.aribowo@gmail.com

Abstract. RNF-1 is an oil well that has been produced since October 1975 on the offshore of the Java Sea. The well was a vertical well, until sidetrack drilling was conducted at October 2000 so RNF-1 become a horizontal well. Perforation of the horizontal segment was done at the interval 7619 – 8638 ftMD. The last production of the well is at August 2010 with 85% of water cut (WC) and the well is being suspended for the back-pressure issue. The company decided to plug the horizontal segment and design workover plan to vertical segment of the well. To minimize risk of uncertainty, an integrated and comprehensive analysis is needed in determining the next production zone target.

The analysis begins with the remaining reserve analysis of RNF-1. After that, analysis to special core analysis (SCAL) data and fluid property data is conducted to build the fractional flow curve. Then, analysis of OH Log (lithology, porosity, and resistivity tool) is done as validation to fluid saturation distribution among the well gained from C/O Log interpretation. This paper presents a novel uncertainty solution, where the value of water saturation (Sw) cut-off we get from fractional flow curve is used to validate the moveable oil saturation of C/O Log. By so, the next pay zone determination for workover plan could be done surely.

After workover plan is executed, it is proved that the production rate is increased from 607 BLPD (WC 85%) to 934.3 BLPD (WC 11.2%) with significant incremental of oil production rate as 736.6 BOPD. In this paper, we can have a view about fluid saturation distribution by C/O Log interpretation. By the validation of C/O Log using cut-off Sw, moveable oil saturation can be determined with minimum uncertainty. This, surely, will give a great feedback to the workover plan, especially for offshore well with higher cost and higher risk.

Keyword: workover, C/O log, fractional flow, validation, risk mitigation

1 Introduction

The upstream segment of oil and gas industry in the offshore is a high risk and high cost industry. The oil and gas activities in offshore give higher uncertainty. Furthermore, production activity, facilities maintenance, drilling activity, piping, also the human resources who worked in the offshore, requires higher cost than in the onshore. Therefore, every activity in offshore, including production optimization through workover, must go through an integrated and comprehensive analysis in order to minimize the uncertainty and to reduce the cost needed.

RNF-1 is an offshore oil well located at the Java Sea, especially north of Madura Island. In the first place, the well is a vertical well, and initially be produced in October 1975 with 788 BOPD of initial oil production rate and 0% of water cut (WC). In October 2000, side-track drilling was conducted, changing the well trajectory to be a horizontal well with total depth 8,683 ftMD/5,827.81 ftTVD. The horizontal traject is divided into two completion section, perforated tubing section at the interval 7,619 - 8,654 ftMD and open hole section at the interval 8,654 - 8,683 ftMD. The last production of this well is on August 2010 with 63 BOPD of oil production rate (607 BLPD and 5.4 MMSCF) and 85% of WC. This section is then being shut-in for back pressure issue. An analysis is done with goals: to fix the cement bonding of existing section (7,619 - 8,683 ftMD) and to find bypassed oil zone at the vertical section.

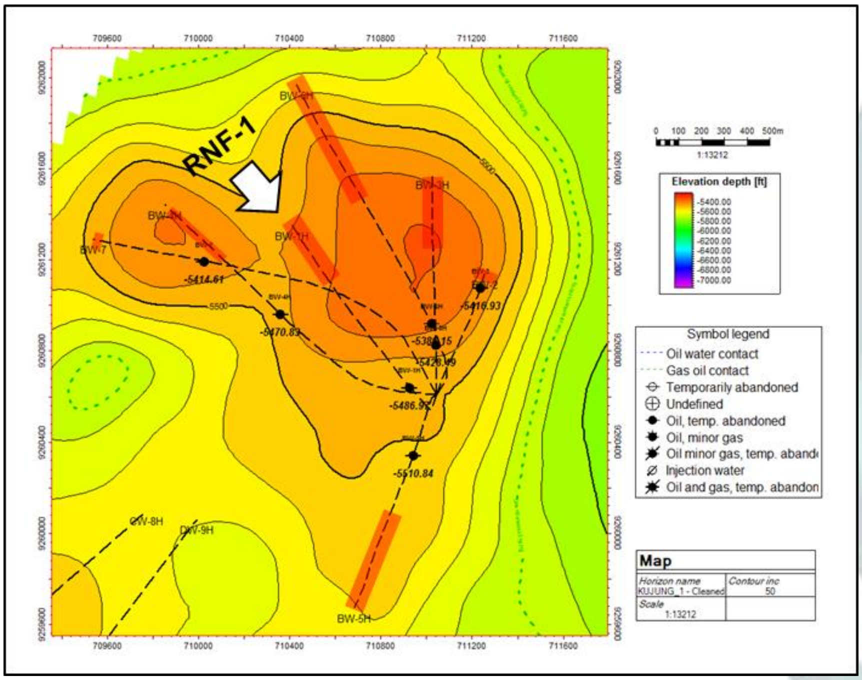

Figure 1. Location of RNF-1 overlay Depth Structure Map

This paper formulates a comprehensive method to determine the bypassed oil zone, which define as "the mobile oil that cannot be produced by existing wells and will be left undrained if nothing is done" (Choon, 2007)[1]. The research on fluid saturation distribution in wellbore by C/O Log in Indonesia's reservoirs has been done by Fox et.al. (1999)[2]. Another research about C/O Log is also done by Simpson et.al. (2001)[3], Chandran et.al. (2002)[4], and then summarized by Ramsin et.al. (2004)[5]. Yet, there is no research that explains about how the validation on C/O Log interpretation is done.

Fractional flow is the data that describe the immiscible displacement process in the reservoir (Sitorus, et.al., 2006)[6]. The fractional flow curve also describes the production performance of moveable oil, especially for the water drive reservoir. The validation of the C/O Log with the fractional flow curve;

which is by applying the value of cut-off moveable oil saturation; is a mitigation step that really necessary to minimize the risk of uncertainty.

2 Literature Review

2.1 Screening of Candidate Wells

Each company will have their own screening method in determining the candidate well for workover. For bypassed oil zone determination, workover well can be screened based on the reservoir characteristic (rock and fluid properties), the reservoir performance, the fluid contact analysis, and the remaining reserve analysis [1].

Dadang Rukmana et.al (2020) [7] from SKK Migas Indonesia has formulated a practical screening method to do the production optimization on mature fields, which is based on the remaining reserve of a reservoir. The remaining reserve can be determined as the difference between in-place area of production well (P1) and the oil cumulative production, include the oil cumulative production of surrounding wells in the radius P1 of the well. After that, the C/O Log is needed to identify the bypassed oil zone. Furthermore, the cement bond improvement is an important requirement to avoid the water channeling through poor cement bond quality.

2.2 Fractional Flow Curve

Fractional flow is a qualitative model that is used to determine the fraction of liquid flow at a certain time and a certain area in a linear water injection system. The model describes the relationship between the total water rate at certain reservoir condition and the water saturation of the reservoir. The assumptions used in fractional flow are [6]:
1. One-dimensional homogeneous system,
2. Isothermal porous medium, and
3. Two phase flow (in this case, oil and water).

The equation for fractional flow is:

$$fw = \frac{1}{1+\frac{k_{ro}\,\mu_w}{k_{rw}\,\mu_o}} \qquad (1)$$

where fw is the fractional flow (fraction), kro is the relative permeability to oil (fraction), krw is the relative permeability to water (fraction), μo is the oil viscosity (cp), and μw is the water viscosity (cp).

Fractional flow can be used to determine the constraint for a well, a layer (reservoir), or a field to be produced economically; by determining the water saturation cut-off (Sw). The cut-off Sw obtained from the fractional flow curve, as the plot of the water saturation and the water cut or fractional flow from special core analysis. When the fractional flow has more than two trends as the effect of rock typing, then the cut-off Sw determination must be separated for each rock type as shown on Figure 2. The limit of the water cut for a field, or a layer, or a well to be produced economically; for example; is 99%.

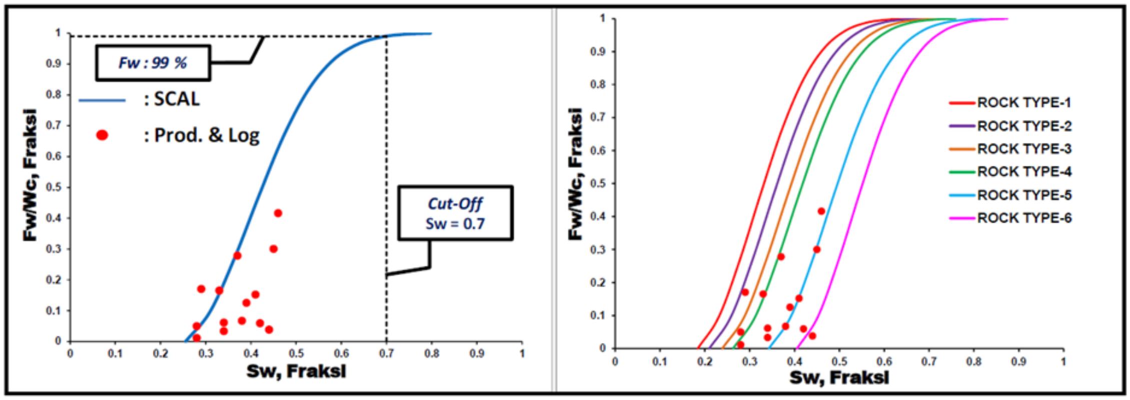

Figure 2. Cut-Off Sw at Fractional Flow 99% [7]

2.3 Carbon Oxygen Log (C/O Log)

The C/O Log use a high energy of neutron generator that are emitted into the formation. The neutron emission generates three types of process: inelastic, elastic and absorption. In the inelastic mode, the tool reads the carbon and oxygen yields and then used them to determine the hydrocarbon volumes. In the elastic mode, neutron will lose its energy and the energy will be absorbed in the form of thermal energy. In this mode, the elemental yields such as silicon, calcium, and other components, can be determined.

Every services company will have their own C/O Log tool specification. However, generally, there are two methods of C/O Log interpretation (Usama Alameedy, 2014) [8]:

2.3.1 Inelastic Interpretation (C/O)

This method of interpretation used the Gamma-ray spectroscopy measurement to directly detect the carbon atom presence in the oil and the oxygen atom presence in the water. The ration of the detected carbon and oxygen then be used to evaluate the oil saturation and not depending on the value of formation water salinity (for low and unknown water salinity formation).

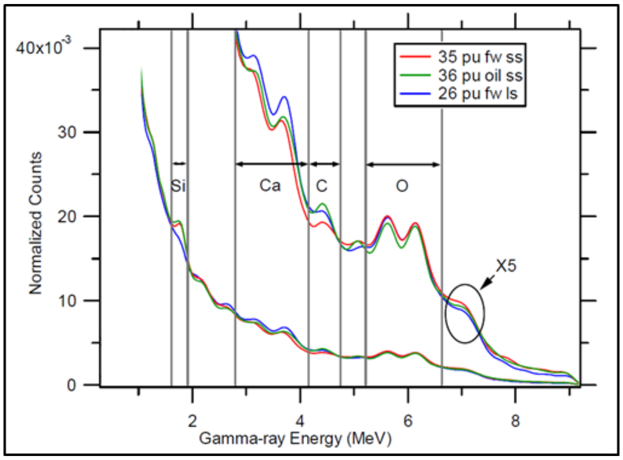

Figure 3. Net Inelastic Gamma Ray Pulse Measurement for 3 Formation [3]

2.3.2 Elastic Interpretation (Sigma)

Thermal capture cross section measurement is used to determine the water saturation in the high water salinity zone. The basic principal is by measuring the difference between the thermal cross section of the saline water and the thermal cross section of the oil, to obtain the value of water saturation.

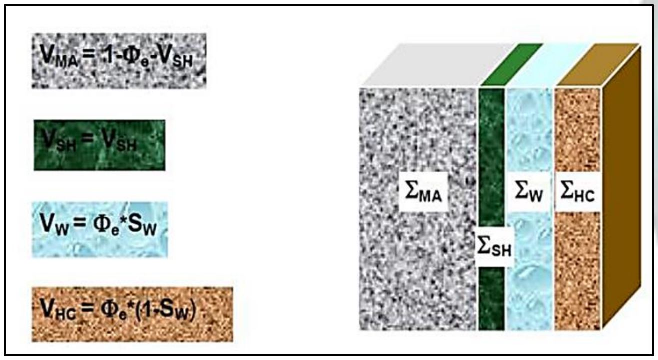

Figure 4. Volumetric Model of The Thermal Capture Cross-Section (Sigma) [8]

3 Methodology

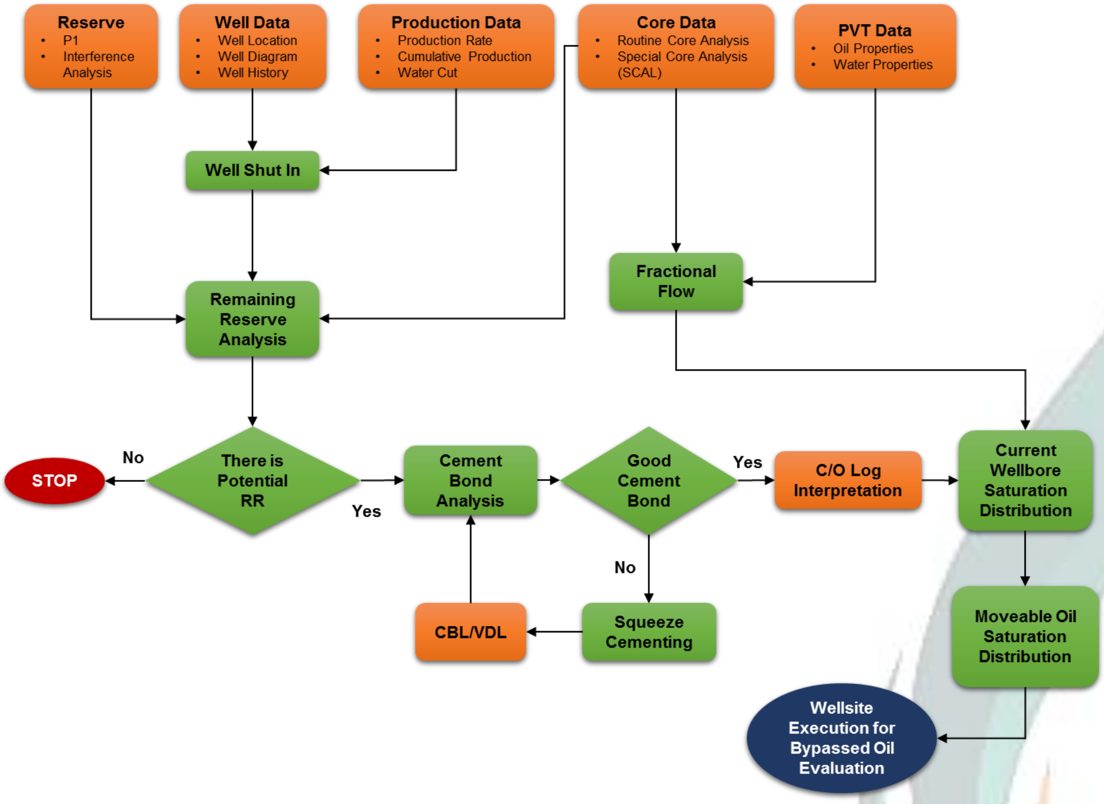

Figure 5. Methodology of Bypassed Oil Zone Determination dan Validation

The research begins by determining the candidate of workover well. The screening of the well is done based on the areal remaining reserve analysis and the cement bond evaluation. After that, fractional flow curve analysis is done to determine cut-off Sw as the constraint between the moveable and the imoveable hydrocarbon saturation. The C/O Log interpretation is done to identify the bypassed oil zone. Next, is the key step, is the validation step of C/O Log interpretation by using the cut-off Sw obtained from the fractional flow curve analysis. The final step is the well site execution for bypassed oil zone evaluation. The methodology of this paper is presented in detail in Figure 5.

4 Result and Discussion

4.1 Screening of Candidate Well

By following the guidelines from SKK Migas [7], the areal remaining reserves analysis of RNF-1 was done. By knowing that there is still economic remaining reserve in the well to be produced, cement bond evaluation for current condition is done make sure that there will be no near well bore water channeling caused by poor cement bonding. Figure 6. shown that the cement bond quality of RNF-1 is good, in a line with the recommended cut-off value of CBL (for good cement bond) which is less than 10 mV.

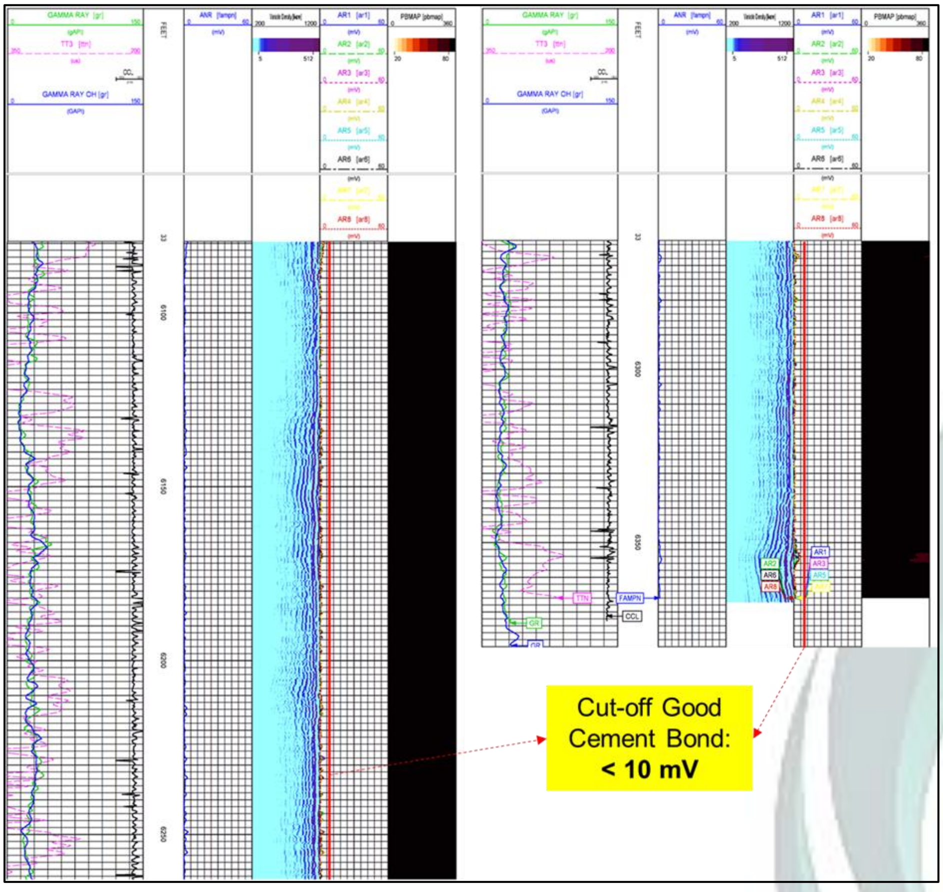

Figure 6. Current CBL-VDL Analysis for RNF-1

4.2 Fractional Flow Analysis

The construction of the fractional flow curve requires special core analysis data (relative permeability to water and relative permeability to oil) and PVT data (oil and water viscosity). Fractional flow is calculated for each value of Sw using equation (1).

Figure 7. shown the result of the fractional flow curve. By applying the constraint 99% of water cut as economic limit (every company will have different constraint value), the cut-off Sw value is 0.62.

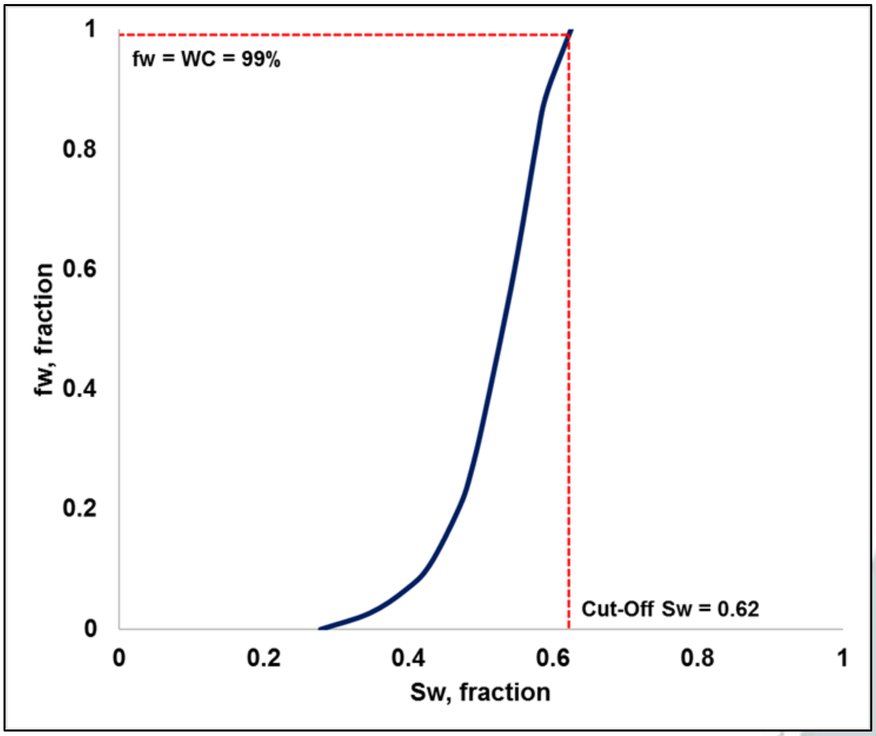

Figure 7. Cut-Off Sw in Fractional Flow Curve Analysis for RNF-1

4.3 C/O Log Interpretation (Optimum C/O Log to Evaluate Current Saturation and to Identify Bypassed Oil Zones)

The interpretation method used for determining the saturation distribution of RNF-1 is inelastic interpretation. Figure 8. shows the interpretation result of the C/O Log for RNF-1. Track-1 shows the reading of the carbon, the oxygen, and the calibration of the both readings. Track-2 shows the depth in ftMD. Track-3 shows the interpretation result of saturation distribution along well bore. In the other words, Track-4 shows the bypassed oil zone along the well bore. Track-5 shows the percentage of fluid and formation lithology. Track-6 shows the comparison of the gamma ray reading of the Open Hole Log and the C/O Log. Track-7 shows the comparison of the porosity reading of the Open Hole Log and the C/O Log. Track-8 shows the mineral content from C/O Log interpretation.

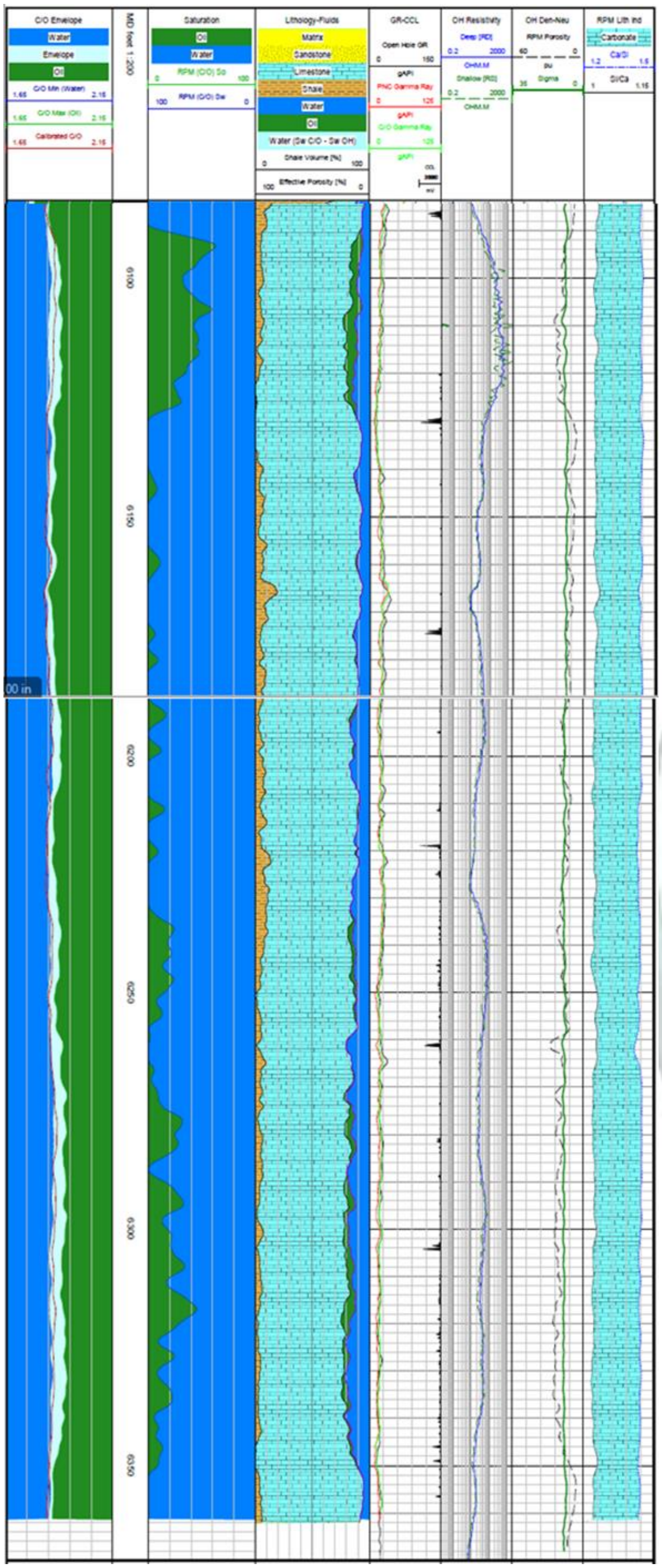

Figure 8. Inelastic Interpretation of C/O Log of RNF-1

4.4 C/O Log Validation with Fractional Flow

C/O Log validation is done by applying the cut-off Sw obtained from Figure 7. to the chart log (Track-3). Figure 9. shows that even there is oil saturation in the lower zone of RNF-1, yet the water saturation is higher than 0.62 so there is no moveable oil saturation in the lower zone.

On the other hand, Figure 10. shows that in the upper zone of RNF-1 there is moveable oil saturation. Therefore, the workover plan for production optimization in RNF-1 is proposed to be done at interval 6,090 - 6,110 ftMD.

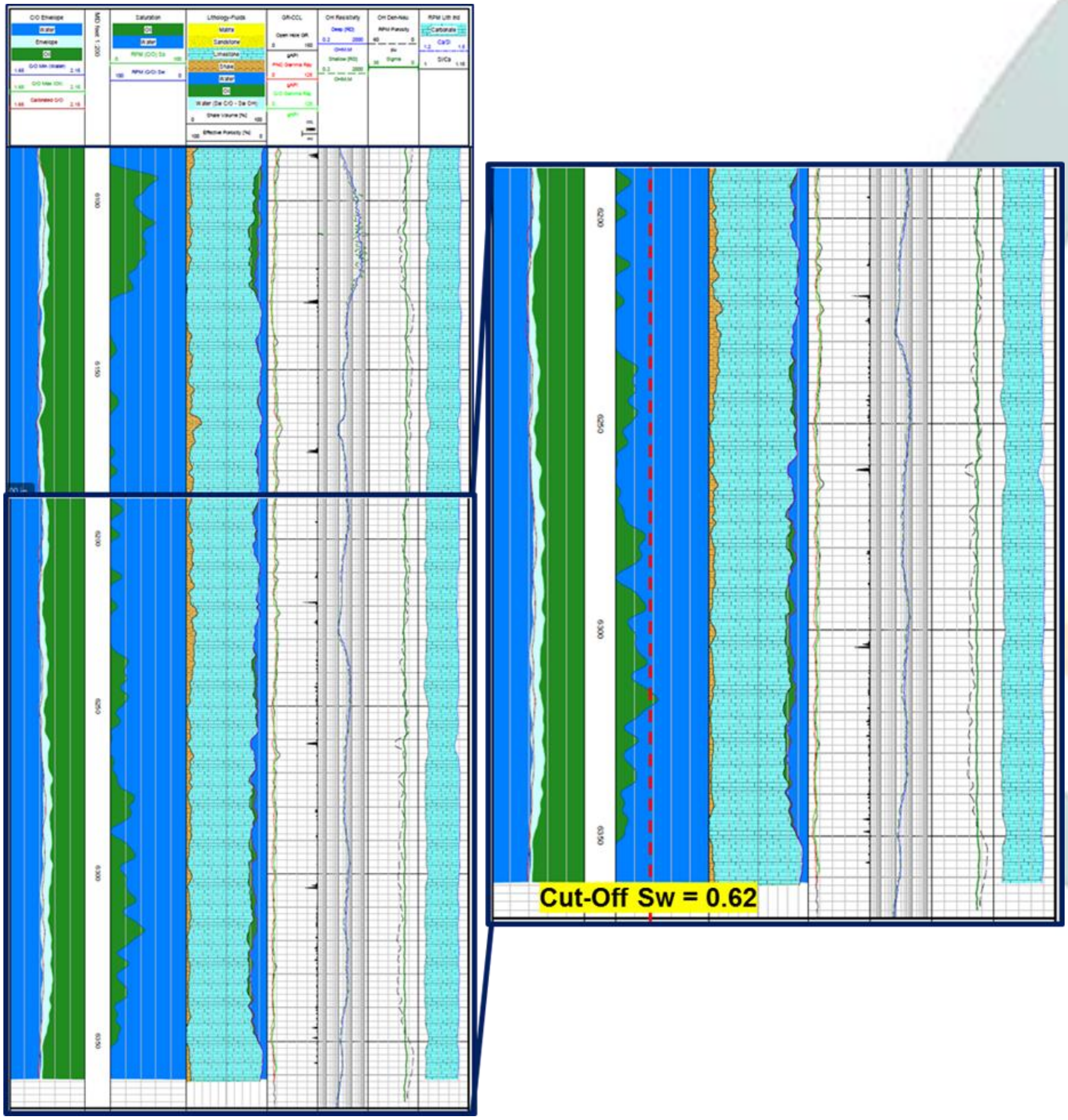

Figure 9. C/O Log Validation with Fractional Flow in Lower Zone where There is No Moveable Oil Saturation

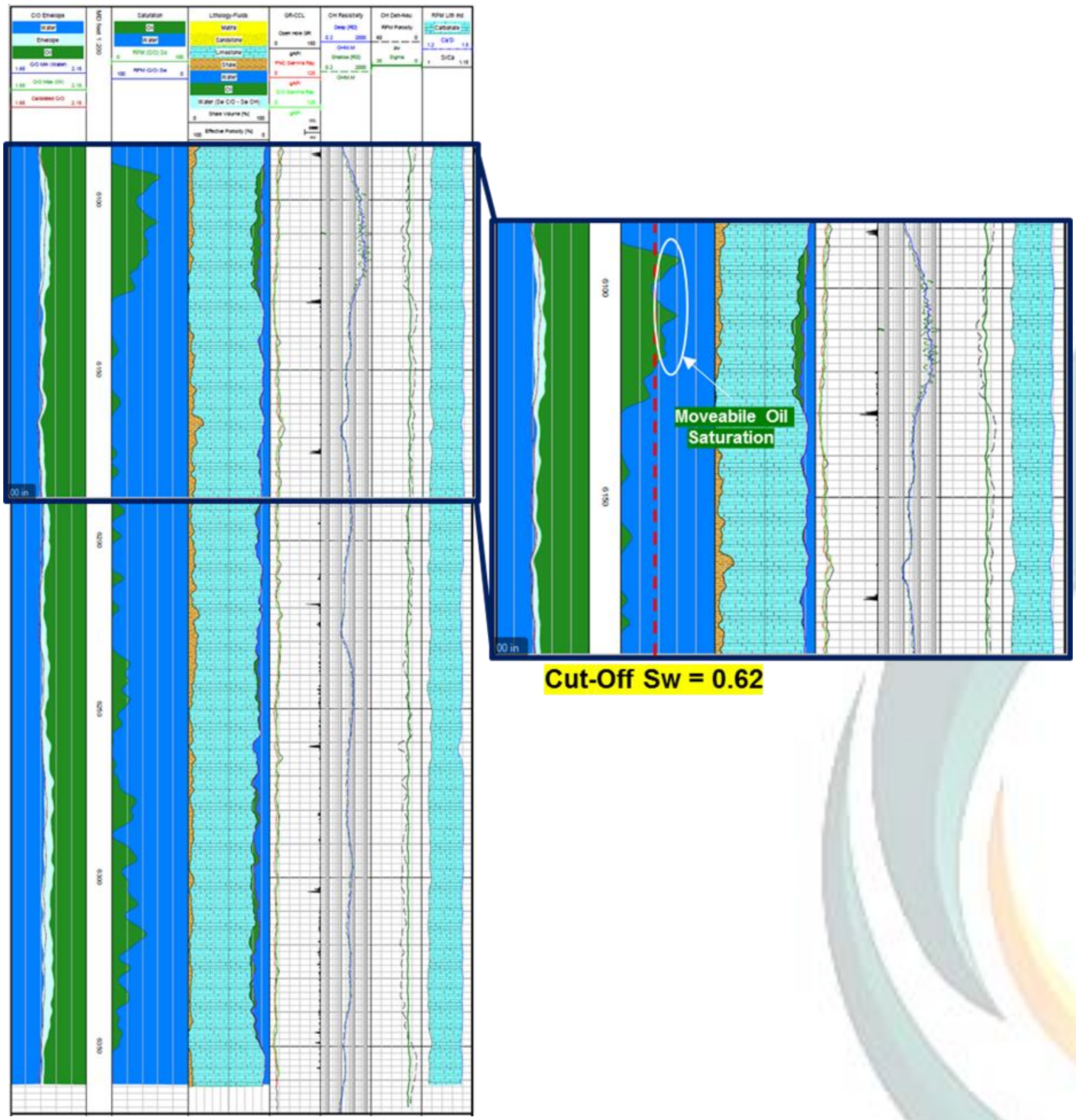

Figure 10. C/O Log Validation with Fractional Flow in Upper Zone where There is Moveable Oil Saturation

4.5 Bypassed Oil Interval Production

The wellsite execution through perforation is done at the proposed interval (6,090 - 6,110 ftMD). The interval has 0.6 of average Sw. The value is lower than the cut-off Sw. After the perforation is done, the production test is conducted and give the initial average result of 934.3 BLPD of liquid production with 829.6 BOPD of net oil production, 11.2 % of water cut, and 0.661 MMSCFD of gas production.

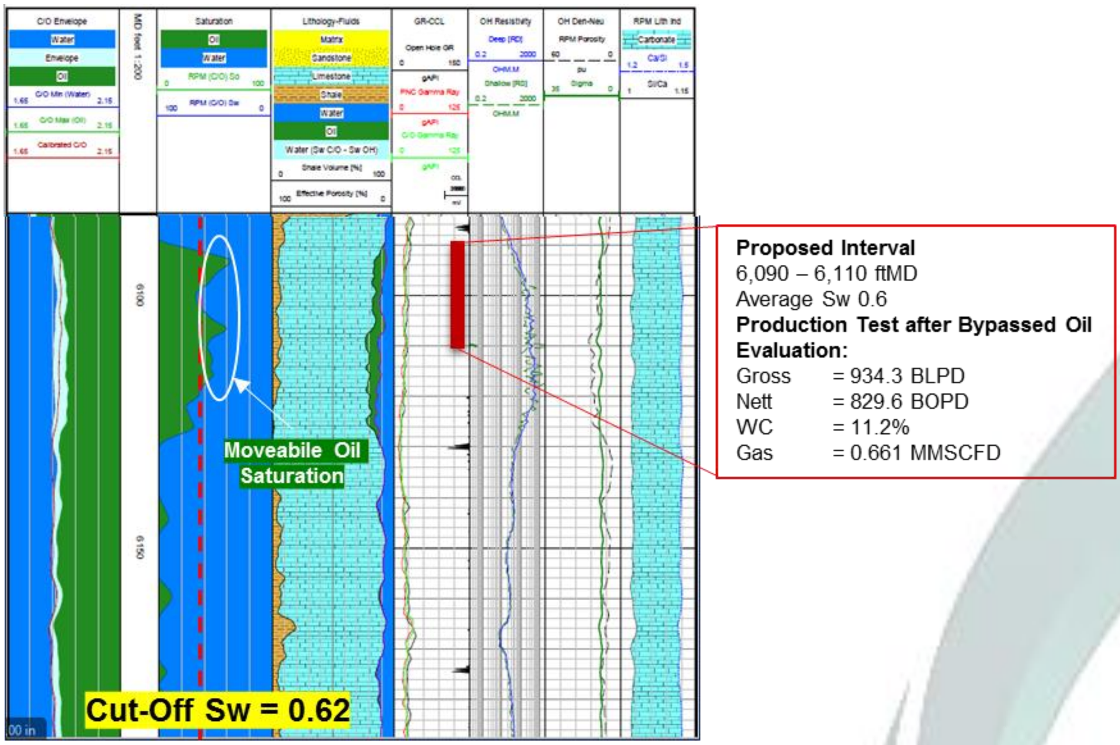

Figure 11. Production Performance of RNF-1 after Wellsite Execution of Bypassed Oil Evaluation

5 Conclusion

Validation of C/O Log interpretation by using cut-off Sw value obtained from fractional flow curve has been successfully proved at RNF-1. Value of cut-off Sw is 0.62. It is mean that C/O Log interpretation for Sw value below 0.62 indicates moveable oil saturation. Proposed interval for the next production zone is 6,090 - 6,110 ftMD with average Sw 0.6. Wellsite execution after bypassed oil evaluation has successfully gives initial average production test result as given: 934.3 BLPD, 829.6 BOPD, 11.2% WC, and 0.661 MMSCFD.

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