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An Integrated Analysis of Shut-in Well Reactivation for Oil Production Optimization in The DLN-11 Well

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ABSTRACT - DLN-11 well was temporarily shut-in due to excessive water production, which became the main issue causing a decline in daily oil production. Therefore, this study conducted an integrated analysis to determine the cause of excessive water production, so that appropriate mitigation measures could be implemented, as well as to formulate a well reactivation strategy aimed at optimizing oil production. The methodology in this study was carried out in an integrated manner through technical and economic evaluations. The technical analysis began with the application of the Chan diagnostic plot as an initial mitigation step, followed by the evaluation of data logging, core analysis data, and production data as advanced mitigation steps to obtain appropriate solutions for addressing production-related issues. In addition, an economic analysis was conducted as a basis for decision-making within a risk management framework. Based on the results of the integrated analysis between the Chan diagnostic plot method and cement evaluation data from Cement Bond Log (CBL), *Variable Density Log* (VDL) dan *Ultra Sonic Imaging Tool* (USIT), the high water cut in DLN-11 well, as a reactivation candidate, was caused by water channeling due to the presence of free pipe conditions, where the cement did not properly isolate the annulus between the casing and the formation. To overcome this issue, remedial cementing was carried out to improve the quality of cement bonding. Furthermore, based on the evaluation results of the C/O Log, DLN-11 well still owns five potential oil-bearing zones that can be produced. The reactivation strategy was implemented by opening the interval of 7927-7942 ftMD, resulting in a production rate of 549 BOPD with a water cut of 82%. The economic analysis results indicate that DLN-11 well yields an NPV of 1,256,000 US$, an IRR of 247.5%, and a Pay Out Time (POT) of 3 months and 16 days. Therefore, from both technical and economic perspectives, the implemented reactivation strategy for DLN-11 well has proven to increase oil production and generate positive economic indicators.

Keywords: shut-in well, excessive water production, reactivation, optimization

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INTRODUCTION

The temporarily shut-in of the DLN-11 well was caused by excessive water production, which led to a decline in oil production. This excessive water production was further influenced by the reservoir's strong water drive mechanism and its carbonate rock characteristics, which are associated with fracture systems. Considering that significant remaining reserves are still present – an important factor in production optimization – a reactivation strategy is required to optimally recover the remaining oil and increase production.

The objective of this study is to identify well-related issues and analyze reservoir characteristics in shut-in well in order to determine operational measures and develop a reactivation strategy that enables optimal production and enhance oil recovery. The novelty of this study lies in its integrated analytical approach. The evaluation is not limited to technical aspect alone but encompasses reservoir characterization, identification and mitigation of well problems, well integrity evaluation, production performance analysis, economic evaluation and risk management analysis as a comprehensive management and future development optimization Furthermore, the results of this integrated study are expected to serve as a reference for reactivating other shut-in wells to optimize production and increase oil recovery.

Estimation of oil and gas reserves is inherently uncertain because oil and gas reserves are dynamic in nature and constantly change over time. Reserves refer to the accumulation of oil and natural gas proven by exploratory drilling, whereas resources represent the total estimated volume of oil, gas, and associated substances within a reservoir at a given time. Recoverable reserves are the portion of hydrocarbon reserves that can potentially be produced using the available technology (Usman 2014; Rukmana et al., 2018). Accurate reserve estimation is crucial for field development planning and cash flow projection to determine economic feasibility (Ahmed., 2006). The recovery factor can be estimated using J. J. Arps method based on the reservoir drive mechanism (Ahmed., 2006; Usman., 2014; Rukmana et al., 2018), special core analysis (SCAL) data through relative permeability versus water saturation relationship (Rukmana et al., 2018), and fractional flow curves versus water saturation (Rukmana et al., 2020).

Excessive water production is a major factor contributing to declining well productivity. It may result from mechanical well problems or reservoir-related issues: water channeling or water coning (Ahmed., 2006; Sukubo et al., 2016; Rukmana et al. 2018). Water coning, multilayer channeling, and near-wellbore problems are the three main causes of excessive water production (Chan., 1995; Sukubo et al., 2016).

Coning occurs when water from below the production zone enters through perforations around the wellbore, reducing oil production (Allen & Robert., 1993). Seven parameters influence water coning, namely mobility ratio, oil zone thickness, the ratio of gravitational to viscous force, well spacing, vertical-to-horizontal permeability ratio, perforation interval, and well production rate (Wojtanowicz et al., 1991; Allen & Robert., 1993; Hani & Sutresno., 2025).

Channeling refers to the movement of formation water from a high-pressure zone into a well through preferential flow path toward a a lower-pressure production zone. These channels may occur due to fracture channeling, high horizontal permeability caused by rock heterogeneity or multilayer systems (Allen & Robert., 1993), or poor cement bonding (Rukmana et al., 2020). Chan (1995) successfully identified the phenomena of coning and channeling using production history data through WOR and WOR derivative (WOR') diagnostic plots, which distinguish bottom-water coning, multilayer channeling, rapid channeling, near-wellbore channeling, and normal displacement behaviour.

Among remedial cementing techniques, squeeze cementing is the most widely applied method in field operations due to its similarity to primary cementing and availability of materials (Diaz et al., 2016). Squeeze cementing involves pumping cement slurry into the wellbore and applying pressure to force it into annulus, cracks or perforations to seal the desired zone (Navid et al., 2015; Fitrianti & Satria, 2020, Diaz et al., 2016). Applications include repairing primary cementing (Izadi et al., 2024), sealing lost circulation zones, repairing casing leaks (Doonechaly et al., 2024), closing incorrect perforation, and isolating non-productive zones Permadi et al., 2010; Muskat et al., 2013; Li et al., 2020.

Cement integrity logs are used to evaluate the quality of cement bonding between the formation (reservoir rock) and casing. Poor cement bonding may allow unwanted fluids to enter the wellbore (Buisine et al., 1990). Common wireline logging tools used for cement evaluation include Cement Bond Log (CBL), Variable Density Log (VDL), Ultrasonic Imaging Tool (USIT) Dwight., 1990; Ashena et al., 2014; Navid et al., 2015; Saimi et al., 2021.

CBL-VDL interpretation is conducted by comparing responses under different conditions, including free pipe (uncemented casing), good cement bonding with casing and formation (well bonded), good cement bonding with casing but poor formation, channeling and microannulus conditions (Dwight 1990). CBL and VDL have been applied to assess the consistency of cement behind the casing to evaluate the separation between reservoir units Ashena et al., 2014; Navid et al., 2015; Saimi et al., 2021. Acoustic energy loss is proportional to the fraction of the casing perimeter protected by the cement, as measured by CBL. The ratio of CBL and VDL provides an assessment of the average volumetric cement in the annular space between the casing and its formation Navid et al., 2015; Suhascaryo et al., 2025.

Crain (2019) describes the use of acoustic amplitude curves to evaluate cement bond integrity. In Cement Bond Logs (CBL) interpretation, low amplitude values indicate good cement bonding (bond index). The bond index serves as a qualitative indicator of the presence of channels within the cement. Furthermore, Hayman et al., (1994) and Schlumberger (2019) obtained interpretation guidelines to classify cement bond conditions, including good cement, channeling, false channels caused by casing wear and casing grooves, gas-related issues, and micro-debonding (dry microannulus).

More advanced analysis utilizes ultrasonic imaging tools designed to measure the acoustic impedance of materials on the outer surface of the casing. This is achieved by using a transducer to emit short acoustic energy pulses with frequencies ranging from 200 kHz to 700 kHz toward the casing. The transducer then acts as a receiver to measure the reflected echoes. Analysis of the return signals can be performed using several approaches, producing outputs such as the acoustic impedance of the material behind the casing and the casing thickness (Kilybay et al., 2017). Good cement condition, based on CBL evaluation, is generally indicated by a reading of less than 10 mV Schlumberger., 2015; Rukmana et al., 2020. This value has been adopted by SKK Migas as a guideline for evaluating cement bond quality in oil wells in Indonesia. If the CBL reading exceeds 10 mV, it may indicate poor bonding which potentially leads to problems such as excessive water production or channeling around the wellbore. In such cases, remedial cementing is recommended for the affected interval (Rukmana et al., 2020).

The C/O log is a logging method to determine oil saturation (So) and water saturation (Sw) under current reservoir conditions. Gas saturation is measured separately using sigma or neutron porosity measurements. Therefore, the So value obtained from C/O log measurements should be corrected or integrated with other methods to accurately determine gas saturation Shouxiang., 2004; Alameedy., 2014; Rukmana et al. 2020. Eyvazzadeh et al., (2004) explain that the C/O log operates by emitting high-energy neutrons into the formation. The neutron interactions produces three types of processes: inelastic scattering, elastic scattering, and absorption. The inelastic spectrum generates carbon and oxygen signals, which are used to estimate hydrocarbon volume.

Economic calculations is essential in oil and gas production operations to determine profitability and other economic indicators. Economic performance depends on production forecast, incurred cost, hydrocarbon prices per unit volume, and the applied fiscal system. Sensitivity analysis is necessary to identify parameters that significantly affect profitability Allison., 1992; Partowidagdo., 2002. Decision-making should be based on sensitivity analysis within a risk management framework. An oil field is considered economically feasible to develop if it provides a short pay-out time (POT), a positive and substantial net present value (NPV), favourable profit -to-investment ratios (PIR), discount profit-to-investment ratio (DPIR), and an internal rate of return (IRR) exceeding prevailing bank interest rates (Partowidagdo., 2002).

Previous studies have evaluated the performance and effectiveness of shut-in well reactivation; however, most of them rely on single or partial analytical approaches, resulting in less comprehensive evaluations Permadi et al., 2010; Alameedy, 2014; Sukubo et al., 2016; Fitrianti & Satria, 2020; Saimi et al., 2021; Doonechaly et al., 2024. Therefore, a more integrated evaluation is required to obtain a clearer understanding of the causes of production decline and to determine appropriate mitigation strategies.

This study aims to identify the causes of excessive water production in the DLN-11 well and to develop an effective reactivation strategy to optimize oil production. The novelty of this research lies in the application of an integrated analytical approach that combines Chan's diagnostic plot, cement evaluation log analysis (CBL-VDL-USIT), reservoir characterization, C/O log interpretation, and economic feasibility analysis. This integrated workflow enables a comprehensive evaluation of well problems, identification of remaining hydrocarbon zones, and assessment of economic viability. The outcomes of this study are expected to provide a practical reference for reactivating shut-in wells and optimizing oil recovery in mature oil fields.

METHODOLOGY

The methodology of this study is designed to address the problems encountered in the DLN-11 well. It consists of data collection and preparation followed by data evaluation and analysis. A schematic overview of the research methodology applied to the DLN-11 well is shown in Figure 1.

Data collection and preparation

The data required to support this research include geological, reservoir, and well data.

- Geological data include reservoir area, which is used to calculate the Original Oil in Place (OOIP), rock characteristics to determine the presence of fractures in candidate reactivation wells, and inter-well correlation data.
- Reservoir data consist of the physical properties of reservoir rocks and reservoir fluids. The rock properties include: porosity (ϕ), permeability (k), water saturation (Sw), net pay zone thickness (h), reservoir pressure (Pi), relative permeability oil and water (kro and krw) obtained from Special Core Analysis (SCAL). The required fluid properties include oil formation volume factor (Boi), oil viscosity (μo), and water viscosity (μw). The summary of the reservoir rock and fluid properties is presented in Table 1.
- Well data include daily production rates (qo, qw), cement evaluation log (CBL-VDL and USIT), well schematic diagram, reserve data and cumulative well production data. The schematic of the DLN-11 well is shown in Figure 2.

Table 1. Physical properties of reservoir rock and fluids

Parameters	Value
Average Porosity (ϕ)	18.6 %
Average Permeability (k)	63.81 mD
Initial Reservoir Pressure (Pi)	2832.5 Psi
Bubble-Point Pressure (Pb)	2154 Psi
Abandonment Pressure (Pa)	328 Psi
Oil Formation Volume Factor (Boi)	1.5919 bbl/stb
Water Viscosity (μ_w)	0.796 cP
Oil Viscosity (μ_o)	0.594 cP

Data evaluation and analysis

Data analysis and evaluation were conducted for the DLN-11 well by compiling the latest production data, identifying well problems, and calculating well recovery factor as a basis for selecting candidate wells for reactivation.

In addition, SCAL data were analyzed to construct fractional flow curves aimed at determining the water saturation cut-off value and estimating the recovery factor value. The fractional flow equation is a quantitative equation (model) used to determine the total fraction of fluid flow at a given time in a linear water injection system (Green & Willhite., 2003; Rukmana et al., 2020). This equation describes the relationship between the total water flow rate and the water saturation value under certain reservoir conditions. For horizontal reservoir conditions, the fractional flow equation is expressed as shows in Equation (1):

$$\text{Fw} = \frac{1}{1 + \frac{k_o}{k_w} \times \frac{\mu_w}{\mu_o}} = \frac{1}{1 + \frac{k_{ro}}{k_{rw}} \times \frac{\mu_w}{\mu_o}} \quad (1)$$

Based on the fractional flow curve obtained from SCAL data, the recovery factor can be determined (Rukmana et al., 2020), as follows:

$$\text{RF (SCAL)} = (1\text{-Swi-Sor})/(1\text{-Swi}) \times 100\% \quad (2)$$

The magnitude of the recovery factor can also be estimated using J. J. Arps material balance method, which is based on the reservoir drive mechanism (Ahmed., 2006; Rukmana et al., 2018). For reservoirs with a water-drive mechanism, Equation 3 is applied.

$$\text{RF} = 54.898 \left(\frac{\emptyset\,(1-S_{wi})}{B_{oi}}\right)^{0.0422} \text{x} \left(\frac{k\,.\,\mu_{wi}}{\mu_{oi}}\right)^{0.0770} \text{x}\; S_{wi}^{-0.1903} \;\text{x}\; \left(\frac{P_i}{P_a}\right)^{-0.215} \quad (3)$$

where RF is the recovery factor (%), φ is the reservoir porosity (fraction), Swi is the irreducible water saturation (fraction), Boi is the oil formation volume factor (bbl/STB), k is the reservoir permeability (mD), μwl is the water viscosity (cp), μoi is the oil viscosity (cp), Pi is the initial reservoir pressure (psi), and Pa is the abandonment pressure (psi).

Meanwhile, the recovery factor at the well scale is calculated using the following equation:

$$\text{RF}_{\text{Well}} = (\text{Np}_{\text{Well}} \,/\, \text{Oil in Place}_{\text{Well}}) \quad (4)$$

One of the key considerations in selecting well candidates is the well recovery factor (RF). An optimal condition for reactivation is achieved when the RF calculated from the SCAL data is greater than the RF obtained from the cumulative production ratio within the well drainage radius (Rukmana et al., 2020; Prayitno et al., 2025).

Identification and analysis of the causes of excessive water production conditions

Identification and analysis of excessive water production in wells are carried out using Chan's diagnostic plot to determine the causes of high- water production problems. This is followed by cement evaluation log analysis (CBL-VDL-USIT) to assess cement quality and bonding behind the casing. If poor cement bonding is identified as the root cause, remedial cementing is performed. The cementing results are then re-evaluated using cement evaluation logs after the remedial operation.

Coning and channeling phenomena can be successfully identified through production history data (Chan et al., 1995). The evaluation of coning or channeling behavior is carried out using Water-Oil Ratio (WOR) and WOR derivative (WOR') graphs. Chan (1995) presented equations for calculating WOR and WOR', as follows:

$$\text{WOR} = \text{qw}/\text{qo} \quad (5)$$

$$\text{WOR'} = (\text{WOR}_{n+1} - \text{WOR}_n)/(\text{Day}_{n+1} - \text{Day}_n) \quad (6)$$

Identification of oil and water zones using water saturation cut off (Sw)

Identification of oil and water zones is carried out using C/O log data after confirming adequate cement quality behind the casing. Hence, C/O log results are

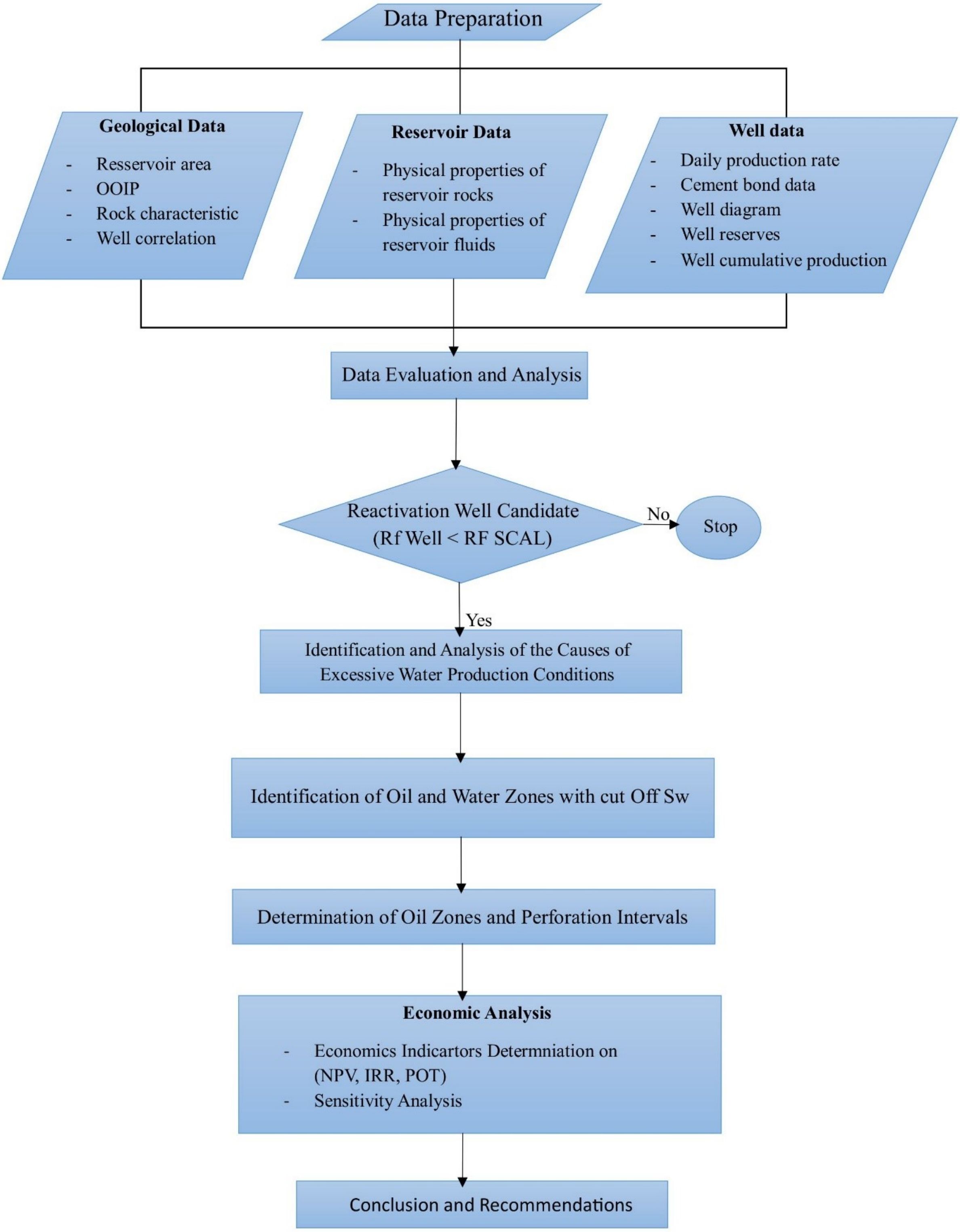


Figure 1. Flowchart of the study

analyzed by applying the water saturation (Sw) cut-off value obtained from the fractional flow curve derived from the SCAL data to distinguish productive oil zones from water zones.

Determination of oil zones and perforation intervals

Based on the results of the CBL-VDL-USIT logs and C/O log interpretation, the target perforation intervals are determined. The selecting oil-bearing zones are then perforated to enable hydrocarbon production.

Economic analysis

An economic analysis is conducted to determine the feasibility of implementing the well reactivation strategy. This includes the assessment of key economic indicators and sensitivity analysis. The economic indicators analyzed are Net Present Value (NPV), Pay-Out Time (POT), and Internal Rate of Return (IRR). The parameters used for the sensitivity analysis include oil price, cumulative oil production, operating cost, and capital investment.

RESULT AND DISCUSSION

Special core analysis (SCAL) data analysis

Special core analysis (SCAL) data are required to construct a fractional flow curve, which is used to determine the water saturation cut-off (Sw). This cut-off assists in distinguishing oil and water zones in the C/O log analysis results and in estimating the recovery factor. The SCAL data were obtained

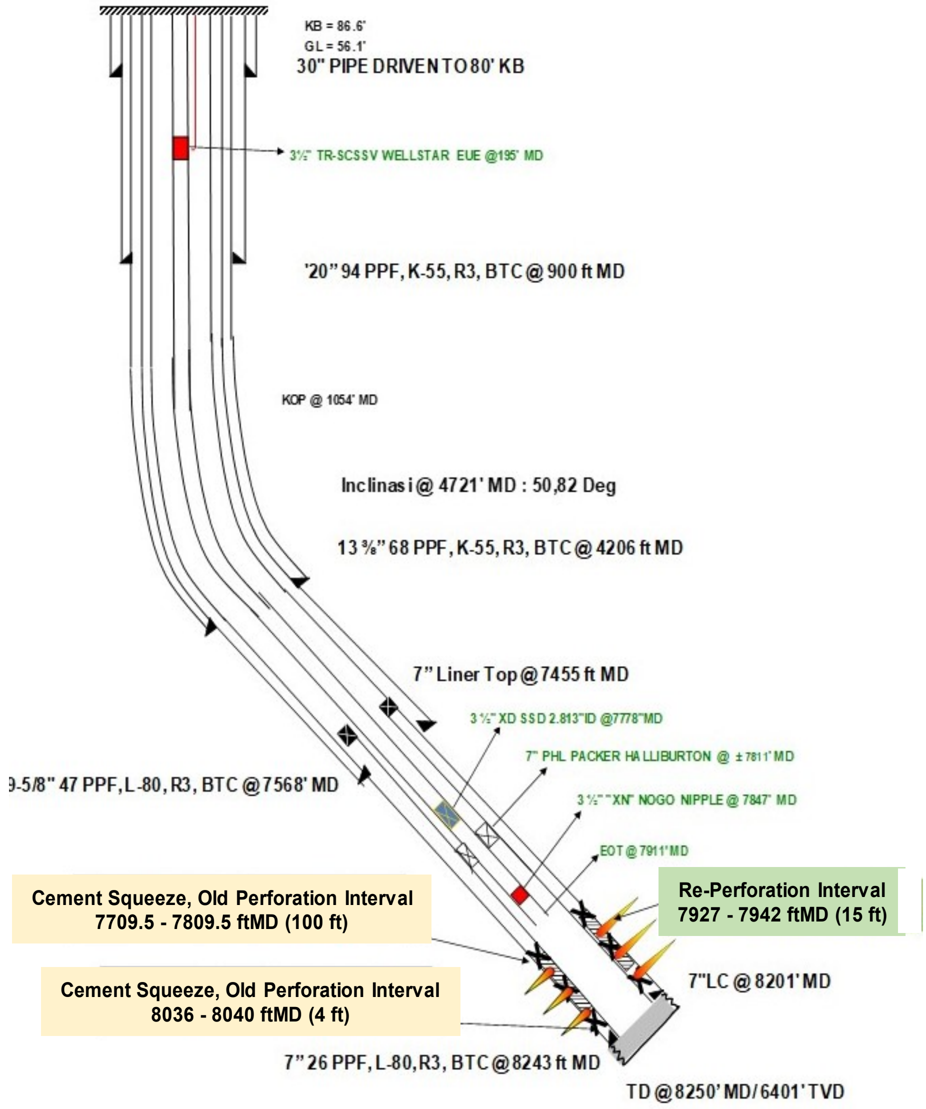


Figure 2. . Schematic completion diagram of the DLN-11 well.

from the DLN-04 well and included relative water permeability to water (krw), relative permeability to oil (kro), and water saturation (Sw). A fractional flow curve (Fw) was generated using Equation (7) as follows:

$$\text{Fw} = \frac{1}{1 + \frac{k_{ro}}{k_{rw}} \times \frac{\mu_w}{\mu_o}}$$

$$= \frac{1}{1 + \frac{0.8417}{0.0006} \times \frac{0.796}{0.594}} = 0.00053 \qquad (7)$$

The fractional flow calculation was performed for each corresponding Sw, krw, and kro value, and the results are presented in Table 2.

Table 2. Results of fractional flow calculations

Sw, fraction	krw, fraction	kro, fraction	Fw, fraction
0.3563	0.0000	1.0000	0.00000
0.3688	0.0006	0.8417	0.00053
0.3842	0.0009	0.7041	0.00095
0.4035	0.0013	0.5471	0.00177
0.4498	0.0029	0.2893	0.00742
0.4742	0.0042	0.1994	0.01511
0.4891	0.0051	0.1597	0.02282
0.5033	0.0063	0.1251	0.03512
0.5166	0.0072	0.0997	0.05111
0.5378	0.0095	0.0668	0.09603
0.5604	0.0124	0.0431	0.17702
0.5804	0.0149	0.0279	0.28487
0.6078	0.0185	0.0153	0.47584
0.6282	0.0214	0.0089	0.64203
0.6386	0.0229	0.0066	0.72131
0.6583	0.0262	0.0037	0.84081
0.6718	0.0283	0.0024	0.89579
0.6901	0.0316	0.0008	0.96707
0.6973	0.0328	0.0000	1.00000

The fractional flow results in Table 2 were then used to create a fractional flow curve by plotting water saturation (Sw) against fractional flow (Fw). This plot was used to determine Sw cut-off value, as shown in Figure 3. The obtained Sw value serves as the cut-off for oil and water zones in the C/O log interpretation.

From the fractional flow curve of Figure 3, a horizontal line is drawn from the 99% water cut point to the right until it interacts the fractional flow curve. From this intersection point, a vertical line is drawn downwards to the Sw axis to determine the corresponding Sw value at 99% water cut. Based on this method, the Sw cut-off value is determined to be 0.7 (70%). The fractional flow calculation results in Table 2 were also used to calculate the recovery factor (RF) using Equation (2). Based on Table 2 and the fractional flow curve in Figure 3, the initial water saturation (Swi) is 0.3563 and the residual oil saturation (Sor) is 0.3026. Therefore, the recovery factor (RF) is calculated as follows:

RF (SCAL) = (1 - Swi - Sor) / (1 - Swi) x 100%
= (1 - 0.3563 - 0.3027) / (1 - 0.3563) x 100% (8)
= 52.97%

Validation of the recovery factor (RF) calculated from the SCAL data was performed using the J. J. Arps material balance method (Equation 9), as follows:

$$\text{RF} = 54.898 \left(\frac{\phi\,(1-S_{wi})}{B_{oi}}\right)^{0.0422} \text{x} \left(\frac{k\,.\,\mu_{wi}}{\mu_{oi}}\right)^{0.0770} \text{x}$$

$$S_{wi}^{-0.1903} \text{ x } \left(\frac{P_i}{P_a}\right)^{-0.215}$$

$$= 54.898 \left(\frac{0.186\,(1-0.3563)}{1.5919}\right)^{0.0422} \text{x} \left(\frac{63.81 \text{ x } 0.796}{0.594}\right)^{0.0770} \qquad (9)$$

$$\text{x } 0.3563^{-0.1903} \text{ x } \left(\frac{2832.5}{328}\right)^{-0.2159}$$

$$= 52.97\%$$

The recovery factor (RF) results obtained from both the SCAL analysis and the J. J. Arps method are consistent. The calculation RF value is used as the basis for selecting reactivation well candidates, where the well RF must be lower than the SCAL-derived RF Rukmana et al., 2020; Prayitno et al., 2025. Based on the screening results which included the latest production data (oil rate and water cut), well status, well recovery factor, and rock characteristics - the DLN-11 well was selected as the primary candidate for reactivation. At the time it was shut-in (February 2019), the DLN-11 well had an oil production rate of 84 BPOD, a water cut of 95%, and a recovery factor of 24.3%. The calculated Original Oil in Place (OOIP) and recovery factor (RF) for DHL-11 well are presented in Table 3.

Identification and analysis of excessive water production

Prior to planning the reactivation of the DLN-11 well, it is necessary to analyze the causes of the

Table 3. Determination results of OOIP and RF for DLN-11 well

Case	Bulk volume (10^6 ft^3)	Net volume (10^6 ft^3)	Pore volume (10^6 ft^3)	HCPV Oil (10^6 ft^3)	OIIP (MMBBL)	Cum. prod. (MMBBL)	Remaining reserve (MMBBL)	RF (%)
1P	2101	599	122	104	12	2.91	9.1	24.3

high water cut. The analysis is carried out using Chan's diagnostic plot. The Water-Oil Ratio (WOR) and its derivative (WOR') were calculated using Equation (5) and Equation (6), and then plotted against cumulative production time, as shown in Figure 4.

The results of the Chan's diagnostic plot analysis indicate whether the high-water cut is caused by coning or channeling. This diagnostic plot provides insights into the past, present, and remaining production potential of the well. The log -log plot of WOR versus time is particularly effective in identifying production trends and diagnosing production mechanism issues. Through this analysis, excess water production can be classified as water coning, water channeling, or other mechanisms.

The interpretation of WOR and WOR', integrated with well mapping data, helps describe the effects of increasing water production and identify remaining reservoir opportunities. The initial WOR value is influenced by the initial WOR value is influenced by the initial water saturation in the productive layer. Variations in WOR over time reflect changes in saturation within depleted layers and allow detection of reservoir flow behavior.

Based on the Chan's diagnostic plot in Figure 4, the WOR curve was relatively stable during the early stage of production. However, over time, the WOR trend increased rapidly and formed a linear slope due to water breakthrough. The WOR' curve also shows a positive slope, suggesting the occurrence of channeling within the perforation interval. To determine the exact cause of channeling, further validation is required using cement bonding and cement evaluation log data to determine whether the produced water results from poor cement bonding or from high water saturation within the reservoir interval.

Analysis of Cement Bonding in DLN-11 Well

Following the Chan's diagnostic plot analysis of the DLN-11, cement bond evaluation was conducted. The objective of this evaluation was to

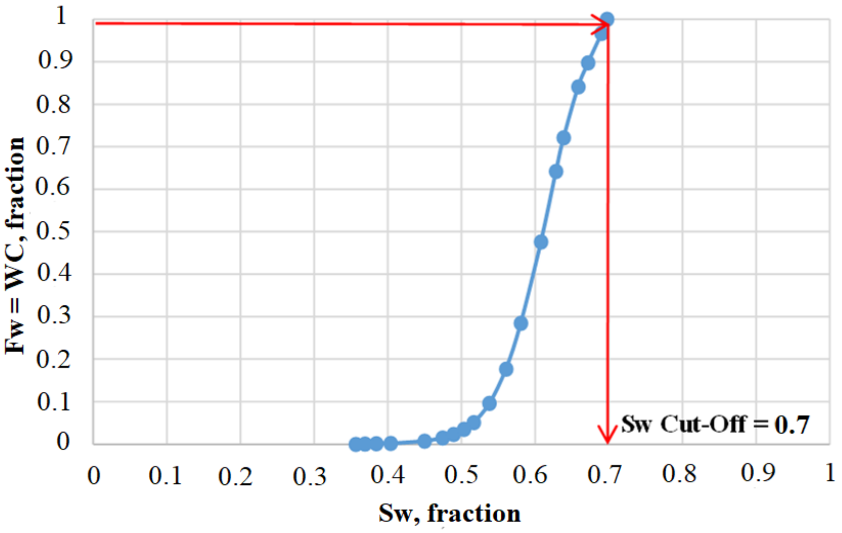


Figure 3. Fractional flow curve used to determine the water saturation cut-off (Sw).
The intersection between the horizontal line drawn from the 99% water-cut level and the fractional flow curve determines the Sw cut-off value used to distinguish productive oil zones from water-dominated zones.

determine whether channeling was caused by poor cement bonding or by reservoir characteristics such as fractures or high permeability zones in the well.

The cement bond evaluation was performed on the results of Cement Bond Log (CBL) - Variable Density Log (VDL) and/or Ultrasonic Imaging Tool (USIT) data log interpretations, depending on the data availability.

The bonding cement evaluation and analysis of the DLN-11 well was conducted using CBL-VDL interpretation results obtained from the 7-inch liner over the interval of 7346-8235 ftMD, as shown in Figure 5. A preliminary observation indicates that the CBL readings for the DLN-11 well exhibit relatively high amplitude value exceeding 50 mV within the 7480-8110 ftMD interval, with slightly lower amplitudes observed at casing collar depths. Considering the CBL cut-off value for good cement binding is 10 mV, it can be concluded that the cement bond within 7480-8110 ftMD interval is poor, indicating free pipe conditions.

The VDL results also show a curve with an almost constant transit time value. This indicates a high casing arrival amplitude and signifies that there is no bond between the casing, cement, and formation. Such a condition suggests that the annular space behind the casing is either empty or poorly cemented. Poor cement bonding in the DLN-11 well allowed water to easily penetrate through the annulus and enter existing perforations, resulting in a significant increase in water production.

To overcome this issue, remedial cementing is needed to improve the cement bond quality behind the casing so that the annulus could be properly isolated. After completing the remedial cementing, CBL-VDL and/or USIT logs were run again to verify the quality of the cement bond. This evaluation ensures optimal conditions for running C/O log, which is used to determine the current fluid saturation conditions in the reservoir.

Remedial cementing of the DLN-11 well was carried out at the existing perforation interval to

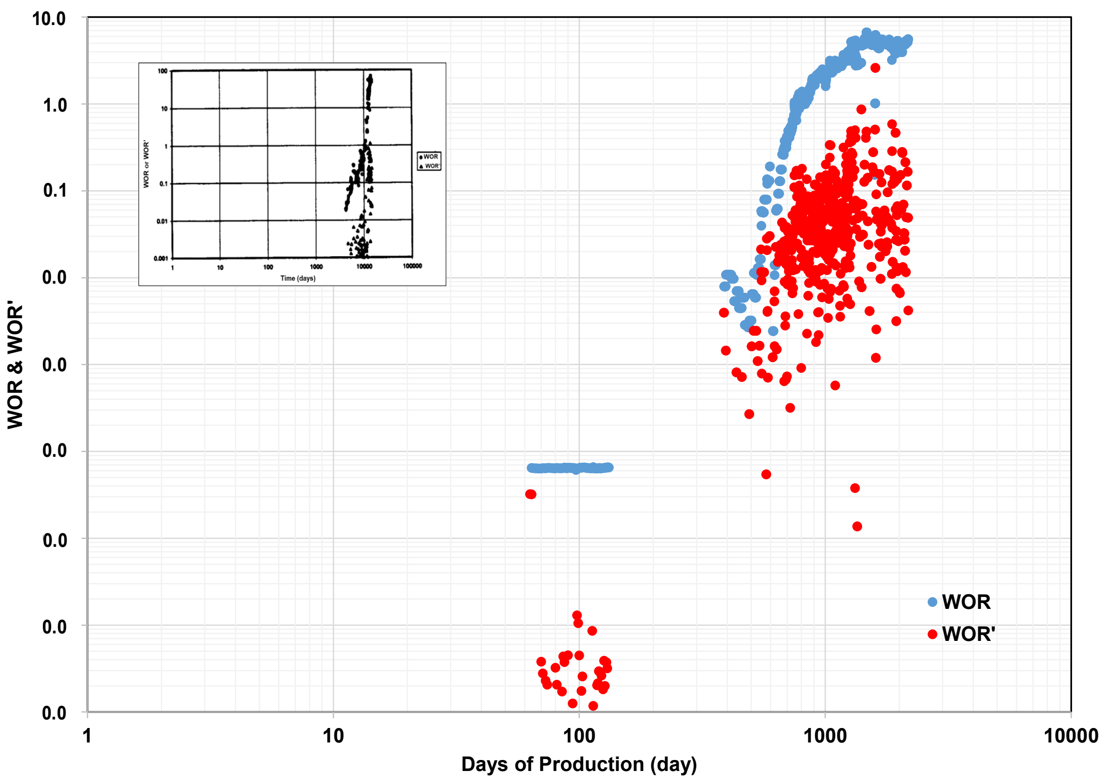
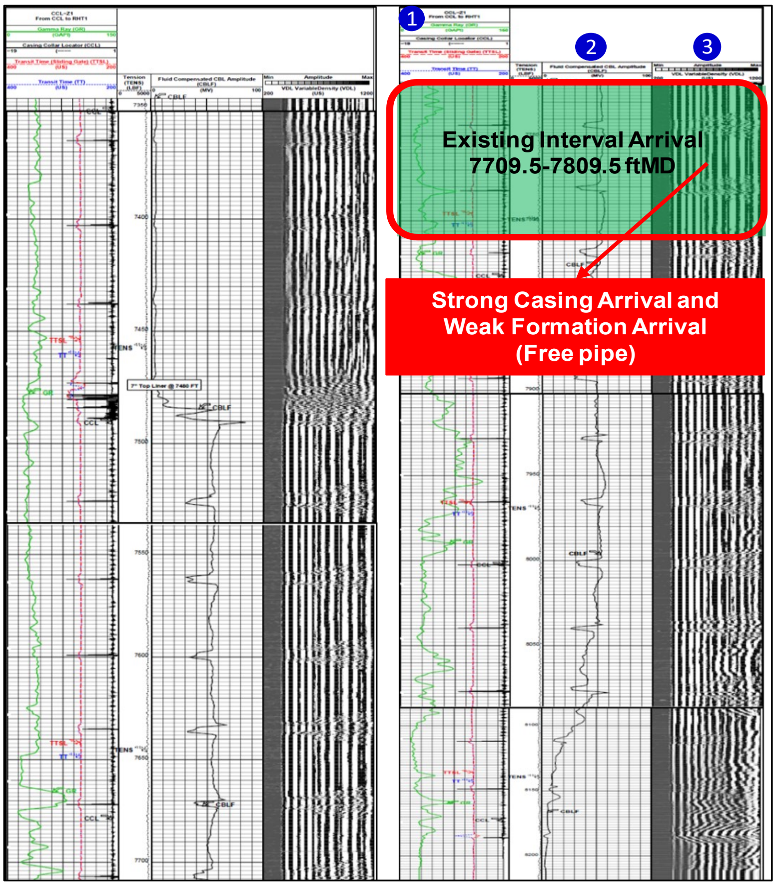
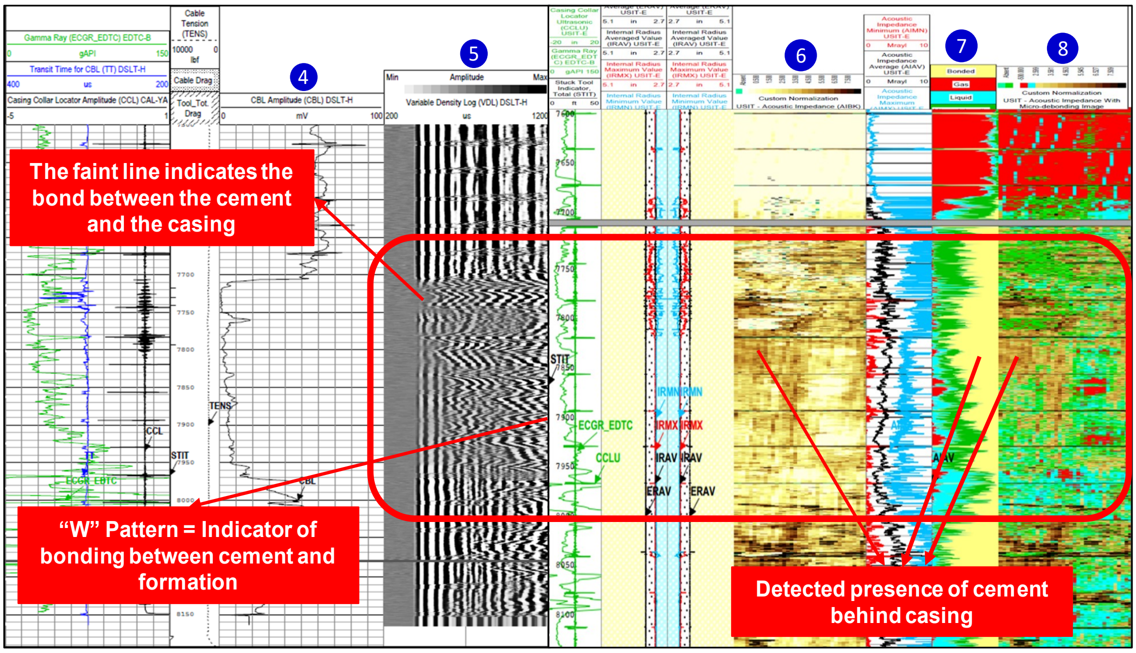


Figure 4. Chan's diagnostic plot for the DLN-11 well showing the relationship between water–oil ratio (WOR) and its derivative (WOR′) versus production time. The increasing trend of WOR and WOR′ indicates abnormal water production behavior associated with water channeling or breakthrough mechanisms, which contribute to excessive water production in the DLN-11 well.


Existing Interval Arrival 7709.5-7809.5 ftMD

Strong Casing Arrival and Weak Formation Arrival (Free pipe)

Figure 5. Cement evaluation log of the DLN-11 well. Column 1 shows the gamma ray (GR), casing collar locator (CCL), and transit time logs. Column 2 presents the cement bond log (CBL), while Column 3 displays the variable density log (VDL) used to evaluate cement bonding conditions behind the casing.


The faint line indicates the bond between the cement and the casing

“W” Pattern = Indicator of bonding between cement and formation

Detected presence of cement behind casing

Figure 6. CBL-VDL and USIT log interpretation of the DLN-11 well after remedial cementing.
The logs show improvements in cement bonding quality after remedial cementing operations, particularly in the 7710–7950 ftMD interval, as indicated by lower CBL amplitudes and improved acoustic impedance responses.

close the perforation interval and improve the cement bond quality. After the remedial cementing was completed, CBL-VDL and USIT logs were run at the 7455-8243 ftMD interval to evaluate the cement bond quality. The CBL-VDL and USIT results after remedial cementing for the DLN-11 well shows in Figure 6. From the CBL-VDL log results (Columns 4 and 5) in Figure 6, an improvement in cement bonding can be observed in the 7710-7950 ftMD interval. At first glance, the cement bonding value at this interval is low because it is below 10 mV. However, this actually indicates improved bonding and a good cement bond between the casing and the formation. In the VDL column, the 7710 - 7800 ftMD interval shows a low casing arrival amplitude and strong formation arrival with a slightly irregular pattern. This means that there is a good cement bond between the casing and the formation. However, in the 7800 - 7950 ftMD interval, the casing arrival is stronger than in the 7710 - 7800 ftMD interval. This suggest that the cement bond quality in the 7800-7950 ftMD interval is slightly inferior compared to that in the 7710 - 7800 ftMD interval.

The interpretation of the USIT log results in Figure 6 (from left to right) is as follows:

- Column 6 shows cement placement behind the casing and the cement impedance value. The higher the cement impedance value, the darker the measurement results. It indicates the better the quality of the cement behind the casing.
- Column 7 shows the combination of cement impedance values and the presence of fluid behind the casing.
- Column 8 shows the combined interpretation of the cement placement and the fluid presence behind the casing.

At a quick glance, Column 6 indicates relatively high cement impedance values in the 7700-7800 ftMD and 8000-8050 ftMD intervals. The darker appearance in these intervals indicates better cement quality behind the casing. The USIT results in column 7 also show increasingly darker colors in the 7700-7800 ftMD and 8000-8050 ftMD intervals, confirming good cement quality in those zones. However, Column 8 indicates micro-debonding (dry annulus) conditions along nearly the entire 7700-8050 ftMD interval, Micro-bonding refers to a gap between the cement and casing that may reduce cement bonding strength. In addition, the casing annulus appears to be partially filled with liquid and gas in some sections, increasing the potential for channeling.

These findings appear inconsistent with the CBL measurement results, which indicate good cement bonding, even though the USIT detected a dry annulus and channeling. Nevertheless, based on the integrated analysis of the CBL-VDL-USIT logs, the remedial cementing work in the DLN-11 well can be considered relatively optimal.

Analysis of DLN-11 well C/O log results

The C/O log (Carbon-Oxygen log) is saturation logging that aims to determine fluid saturation in production wells under current conditions (current saturation). From the C/O log results that have been applied with a certain Sw cut-off value, it is possible to identify which layers or intervals are predominantly water-filled and which still contain movable oil that can be produced. The C/O log data were analyzed to determine zones with remaining oil potential and zones which are already water-filled. The analysis of prospective zones was performed by applying a cut-off value of Sw = 0.7 or 70%. This cut-off assumes that when the water saturation (Sw) reaches 70%, the water cut (WC) approaches 100%.

Conversely, if the Sw value in a zone below 70%, the interval is considered to still contain movable oil saturation that can be produced. The C/O log was run in the DLN-11 well over the of 7770 - 8200 ftMD interval. After applying the Sw cut-off of 0.7 (Sw = 70%), five potential oil zones were identified at the following intervals: 7709 - 7718 ftMD, 7810-7830 ftMD, 7850-7915 ftMD, 7927-7942 ftMD, and 7955 - 7965 ftMD.

It was observed that the previous perforation interval at 7709.5 - 7809.5 ftMD was predominantly water-filled, with only a small amount of movable oil remaining. This is indicated by Sw value exceeding the cut-off, which explains the high-water production from this interval. The

C/O log interpretation results after applying the Sw cut-off are shown in Figure 7.

In Figure 7, the log chart consists of eight columns with the following descriptions:

- Column 1 shows the C/O reading calibration results.
- Column 2 shows the depth.
- Column 3 shows the water saturation reading from the C/O log.
- Column 4 shows the porosity and mineralogy readings.
- Column 5 shows a combination of GR, CCL, and Caliper.
- Column 6 shows the resistivity log.
- Column 7 shows the porosity log.
- Column 8 shows the uncertainty level of the C/O log interpretations.

Column 3 shows the results of water saturation interpretation at each depth. Dark blue indicates initial water saturation based on open-hole logs, light blue represents current water saturation, and green indicates current oil saturation.

Based on the Sw cut-off analysis, several oil zones and water-dominated zones were identified. The previous perforation interval at 7709.5-7809.5 ftMD still contains movable oil in the upper portion; however, the lower portion is already water-filled as indicated by Sw values above the cut-off. This condition explains the significant increase in water production in the DLN-11 well.

A summary of the evaluation and analysis of the prospective zones in the DLN-11 well is presented in Table 4. Based on the C/O log results summarized in Table 4, the 7927-7942 ftMD interval was selected as the target interval to be opened. This interval was selected because it exhibits relatively high oil saturation (approximately 40-65%), good porosity values (approximately15-25%), and a CBL value of less than 10 mV, indicating good cement bond despite the presence of micro-debonding conditions behind the casing.

Reactivation of DLN-11 well

One of the production optimization efforts for the DLN-11 well involved performing remedial cementing to improve the quality of cement bonding between the casing and the formation. This was followed by running a C/O log to determine the current fluid saturation and identify prospective zones containing movable oil. After identifying the prospective zones, perforation of the selected interval was conducted to enable oil production to surface and increase overall oil output from the DLN-11 well.

The evaluation of the C/O log in the DLN-11 well revealed five potential oil zones. An integrated analysis of the C/O log and CBL-USIT results was then performed to determine the most suitable perforation intervals. The evaluation results of potential oil zones in the DLN-11 well are presented in Table 5.

Based on the integrated analysis of cement evaluation log and C/O log results summarized in Table 5, the 7927-7942 ftMD interval was selected as the target interval to be opened. Meanwhile, the lowest interval (7955-7965 ftMD) was not considered a candidate for production perforation due to total loss issues, which caused high uncertainty in C/O log readings. Based on the analysis, the selected production perforation interval is 7927-7942 ftMD, with an oil saturation value of 40-65% and fairly good porosity properties. An alternative candidate production perforation interval is 7810-7830 ftMD due to its relatively high oil saturation and reservoir properties comparable to those of the 7927-7942 ftMD interval.

The DLN-11 well began production on June 5, 2012, with an initial oil rate of 2,363.35 BOPD. Water production started on June 27, 2013, at 26 BWPD and continued to increase, reaching 1230 BWPD on February 4, 2019. Based on the production history of the well, water breakthrough occurred approximately one year after the well was put on production. The DLN-11 well was shut-in in February 2019, producing 84 BOPD of oil and a water cut of 95%.

After selecting the new production interval, production perforation was continued at the 7927-

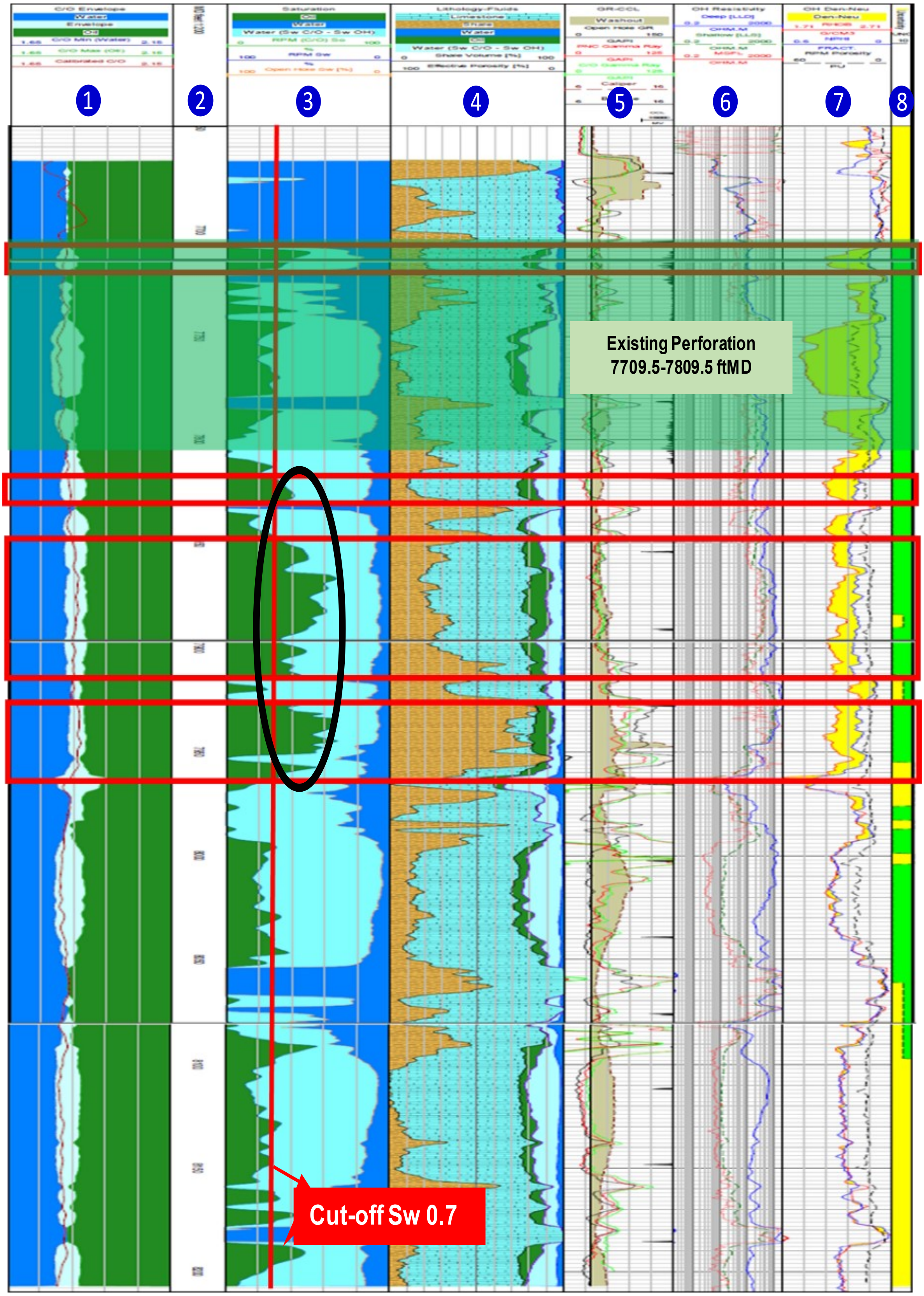


Figure 7. C/O log interpretation of the DLN-11 well. The log chart consists of eight columns: (1) C/O calibration results, (2) depth, (3) water saturation derived from C/O log interpretation, (4) porosity and mineralogy logs, (5) gamma ray (GR), casing collar locator (CCL), and caliper logs, (6) resistivity log, (7) porosity log, and (8) uncertainty level of the C/O log interpretation.

Table 4. Summary of prospect zone evaluation and analysis at DLN-11 well

No	Interval, ftMD	SEvaluation and analysis results
1	7709-7718	Oil saturation is good (30 - 50%), with good porosity (15 - 20%)
2	7810-7830	Oil saturation is fairly good (30 - 40%), with good porosity (15 - 20%)
3	7850-7915	Oil saturation is good (35 - 65%), with medium porosity (10 - 15%)
4	7927-7942	Oil saturation is good (40 - 65%), with good porosity (15 - 25%)
5	7955-7965	Oil saturation is good (30 - 50%), total loss occurred at a depth of 7960 ftMD

Table 5. Results of C/O log and CBL-USIT evaluations and analysis of DLN-11 well

No	Interval, ftMD	C/O Log Evaluation and Analysis	CBL-USIT Evaluation and Analysis
1	7709-7718	Oil saturation is good (30 - 50%), with good porosity (15 - 20%)	CBL value < 10 mV, USIT indicates poor cement impedance and micro-debonding, which may increase the potential for micro-channeling.
2	7810-7830	Oil saturation is fairly good (30 - 40%), with good porosity (15 - 20%)	CBL value < 10 mV, USIT shows fairly good impedance values; however, there is potential for micro-channeling due to micro-debonding conditions
3	7850-7915	Oil saturation is good (35 - 65%), with medium porosity (10 - 15%)	CBL value < 10 mV, USIT indicates micro-debonding and annulus filled with fluid (gas and liquid) in the annulus.
4	7927-7942	Oil saturation is good (40 - 65%), with good porosity (15 - 25%)	CBL value < 10 mV, USIT shows cement filling the annulus; however, micro-debonding conditions are present and may increase the potential for micro-channeling.
5	7955-7965	Oil saturation is good (30 - 50%), with total loss at a 7960 ftMD.	CBL value 10 - 20 mV, USIT shows fluid- filled annulus conditions and micro-debonding.

7942 ftMD interval. From this interval, the well produced 549 BOPD of oil and 2813 BWPD of water, resulting in a water cut of 82%. The production performance of the DLN-11 well before and after reactivation is shown in Figure 8.

The high water cut and water rate remain undesirable. Based on the evaluation results, these conditions are attributed to suboptimal cement bonding and micro-debonding, which allowed water to migrate through the casing annulus into the wellbore and be produced to the surface.

Economic analysis

In addition to technical considerations, economic evaluation is necessary to assess project feasibility using economic indicators such as NPV, POT, IRR, and PI. The economic analysis was carried out on a single-well basis to evaluate the success of the DLN-11 well reactivation under a Production Sharing Contract (PSC) scheme. The data required for the economic analysis are presented in Table 6. Economic indicators are parameters used to determine whether a project is financially feasible. The economic performance of DLN-11 well was evaluated based on a total project investment of US$ 508,000 and an incremental oil production rate of 549 BOPD. The calculation results are presented in Table 7. Based on Table 7, the DLN-11 well yields an NPV of US$ 1,256,000 over a one-year project life. The pay-out (POT) is 0.29 years or 3 months and 16 days.

Table 6. Economic calculation data

Data	Value		Remark
Project life	12	month	Minister Decree of Energy and Mineral Resources No. 134/2020
Decline Rate	40	%/year	
Oil Price (ICP)	36.7	US$/bbl	
OPEX	8.45	US$/bbl	

Table 7. Economic calculation results for the DLN-11 well

Parameters	Unit	Value
Total Gross Revenue	US$ '000	4,738
Operating Expenditure (OPEX) and Depreciation	US$ '000	1,598
Contractor's Share	US$ '000	1,256
Government's Share	US$ '000	1,884
Net Present Value (NPV) (DF 10%)	US$ '000	1,256
Internal Rate of Return (IRR)	%	247.5
Payback Period (POT)	Years	0.29
Profitability Index (PI)	US$/US$	3.47

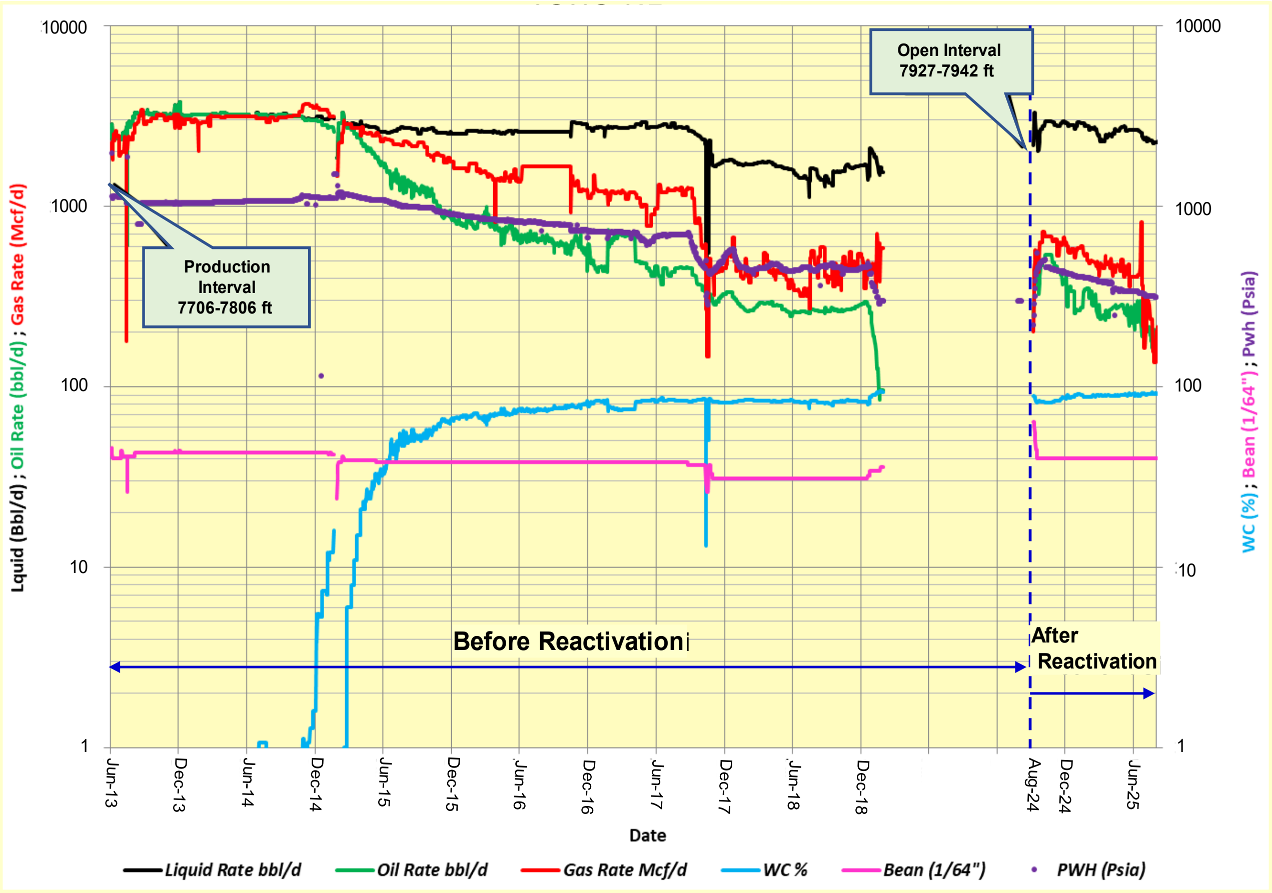


Figure 8. Production performance of the DLN-11 well before and after reactivation. The figure compares oil rate and water production trends before shut-in and after reactivation, demonstrating the improvement in oil production following remedial cementing and perforation of the new production interval.

Sensitivity analysis was conducted to determine the effect of changes in key parameters on project profitability, as reflected in the economic indicators. The parameters analyzed include cumulative oil production, oil price, operating (lifting) cost, and capital investment.

This sensitivity analysis was performed by applying presented variations of -10%, -20%, and -30% and +10%, +20%, and +30% to the selected economic parameters. The sensitivity analysis results for the economic parameters of DLN-11 well were then plotted in spider diagram to observe the sensitivity of NPV, IRR, and POT as shows in Figure 9 through 11, respectively. Based on the spider diagram for the DLN-11 well (Figures 9-11), it can be shown that the parameters with the greatest influence on the economic indicators are oil price and cumulative oil production, followed by operating (lifting) costs and investment. Changes in oil price and cumulative oil production greatly affect the economic indicators (NPV, POT, and IRR).

An increase in cumulative oil production results in a higher NPV and a faster pay-out time (POT). Similarly, the higher the oil prices lead to a greater NPV and a faster POT. In contrast, variations in investment cost and lifting cost do have a less significant impact on the economic indicators. The lower investment cost increases the NPV and shortens the pay-out time. Likewise, lower lifting costs, result in a greater NPV and a faster of POT.

CONCLUSION

Based on the results of data processing, analysis, and discussion, several conclusions can be drawn from this study. The integrated analysis using Chan’s Diagnostic Plot and cement evaluation logs (CBL–VDL–USIT) indicates that excessive water production in the DLN-11 well

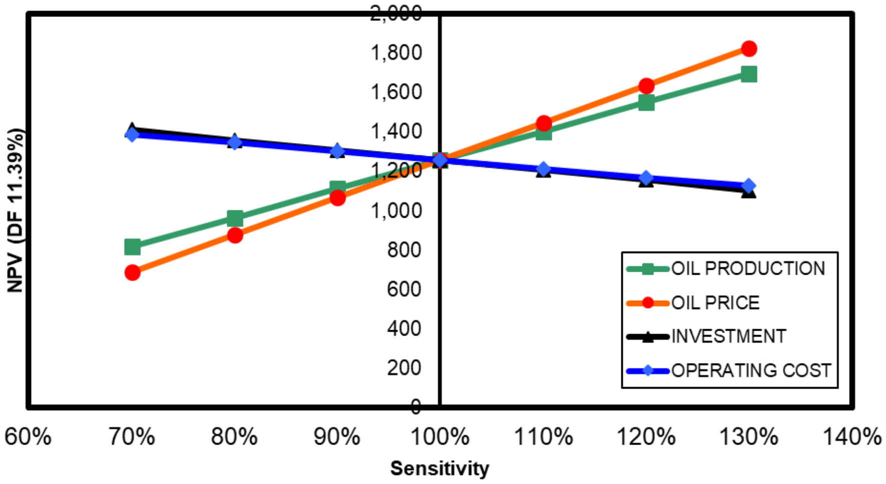


Figure 9. Spider diagram showing the sensitivity of net present value (NPV) at a discount factor of 11.39% to variations in major economic parameters for the DLN-11 well reactivation project. The parameters analyzed include oil production, oil price, investment cost, and operating cost. The increasing trends in oil production and oil price significantly improve the project NPV, whereas higher investment costs reduce economic returns.

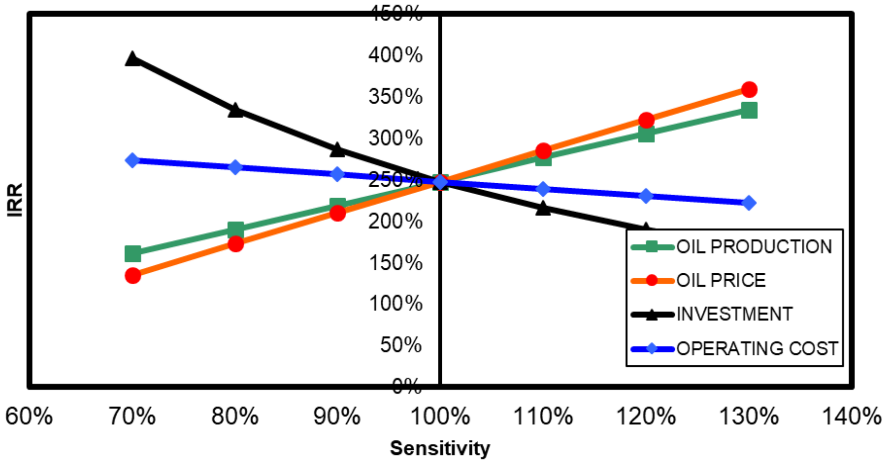


Figure 10. Spider diagram for IRR sensitivity of DLN-11 well

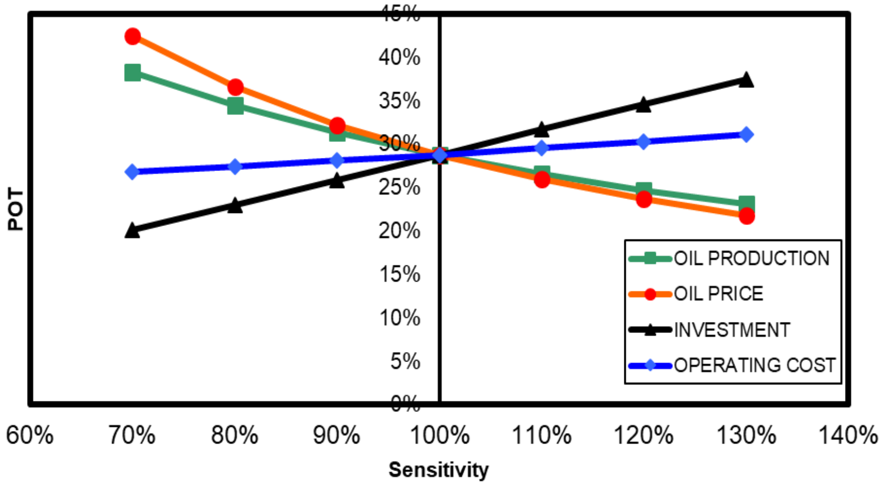


Figure 11. Spider diagram showing the sensitivity of pay-out time (POT) to changes in major economic parameters for the DLN-11 well reactivation project. The parameters analyzed include oil production, oil price, investment cost, and operating cost. The results indicate that POT is highly sensitive to variations in oil production and oil price, whereas operating cost variations have a comparatively lower impact on project economics.

was caused by rapid channeling due to free pipe conditions, where the cement failed to seal the annulus between the casing and the formation. To mitigate this water channeling problem in the shut-in candidate well, remedial cementing was conducted to improve the cement bond quality, followed by cement evaluation logging (CBL–VDL–USIT) to assess the effectiveness of the remedial operation.

Based on the C/O log evaluation performed after the remedial cementing operation, five potential oil zones were identified in the DLN-11 well at the following intervals: 7709–7718 ftMD, 7810–7830 ftMD, 7850–7915 ftMD, 7927–7942 ftMD, and 7955–7965 ftMD. The selected reactivation strategy involved remedial cementing and perforation of the most prospective oil zone at 7927–7942 ftMD, which resulted in an oil production rate of 549 BOPD with a water cut of 82%. Economic evaluation also indicates that the reactivation of the DLN-11 shut-in well is economically feasible, yielding a net present value (NPV) of US$1,256,000, an internal rate of return (IRR) of 247.5%, and a pay-out time (POT) of 3 months and 16 days. Based on the discussion and conclusions of this study, several recommendations can be proposed. During remedial cementing operations in candidate reactivation wells, suboptimal cement bonding conditions may still occur and potentially cause water channeling, resulting in less optimal oil production. Therefore, improvements in cementing design and more comprehensive evaluation methods are required to ensure that remedial cementing operations effectively enhance cement bond quality. In addition, further analysis is recommended to determine the critical water production rate in order to prevent rapid water breakthrough to the surface, particularly in wells that still exhibit relatively low water cut conditions.

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GLOSSARY OF TERMS AND SYMBOLS

Terms & Symbols	Definition	Unit
BOPD	Barrel oil per day	
BWPDCBL	Barrel water per day Cement bond log	
CCL	Casing collar locator	
C/O	Carbon-oxygen	
DPIR	Discount profit to investment ratio	
Fw	Fractional flow	fraction
HCPV	Hydrocarbon pore volume	ft^3
IRR	Internal rate of return	%
NPV	Net present value	US$
OOIP	Original oil in place	STB
POT	Pay out time	Years
PIR	Profit to investment ratio	
PSC	Production sharing contract	
RF	Recovery factor	fraction
SCAL	Special core analysis	
USIT	Ultrasonic imaging log	
VDL	Variable density log	
WC	Water cut	fraction
WOR	Water oil ratio	
WOR'	Water oil ratio derivative	
ϕ	Porosity	fraction
μo	Oil viscosity	cP
μw	Water viscosity	cP
Bo	Oil formation volume factor	bbl/stb
h	Net thickness	ft
k	Permeability	mD
ko	Oil effective permeability	mD
kw	Water effective permeability	mD
kro	Oil relative permeability	fraction
krw	Water relative permeability	fraction
Np	Oil cumulative production	bbl/day
Pi	Initial reservoir pressure	Psi
Pa	Abandonment pressure	Psi
So	Oil saturation	fraction
Sw	Water saturation	fraction
Swi	Initial water saturation	fraction
Sor	Residual oil saturation	fraction
qo	Oil production rate	BOPD
qw	Water production rate	BWPD

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