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Evaluation and Reactivation Strategy of Shut-In Wells Due to High Water Cut to Improve Oil Production in Bayu Field: Case Study of Bayu-N3 Well

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Abstract: Bayu-N3 was being shut-in (S/I) due to excessive water production (high water cut well) as the main cause of the high daily production decline of the well. Therefore, an integrated analysis was conducted to identify the source of excessive water production and handle the problem. The reactivation strategy of Bayu-N3 was well planned to solve and optimize the oil production of the well. Based on integrated analysis of Chan's diagnostic plot and cement evaluation log (CBL-VDL-USIT) data, the source of excessive water production at Bayu-N3 is water channeling, caused by the free pipe condition as the result of poor cement bonding between the casing and the formation. To handle the water channeling problem, remedial cementing was conducted to repair the cement bonding quality. Based on the C/O log evaluation at Bayu-N3 as the reactivation well candidate, there are six potential oil zones to be produced. The reactivation strategy was executed by perforating at interval 6544-6564 ft-MD and resulting 1602 BOPD with 0% of water cut. The economic analysis of the reactivation shows that Bayu-N3 well gives 5153 MUSD of NPV and 538% of IRR with one month and 29 days of POT. It is shows that the reactivation strategy of Bayu-N3 is technically and economically able to improve the oil production and gives good positive economic indicators. Furthermore, the successful of reactivation strategy in Bayu-N3 well could be used as reference to be implemented for other candidate wells in Bayu Field.

Keywords: High Water Cut, Shut-in Well, Reactivation, Potential Oil Zone

1. Introduction

Bayu field is a mature oil field located in the North East Java Basin, in the work area of PT. Pertamina EP Asset 4. The field was discovered in 2001 by the successful hydrocarbon finding through Bayu-1 exploration well. The reservoir at Bayu Field is a reef build-up carbonate reservoir from Tuban Formation. The first production of the field is from Bayu-N1 and Bayu-N2 in 2004, with 297 MMSTB oil in place. Currently, the field has 35 development wells with 114 MMTSB of cumulative oil production and 37 MMSTB of remaining reserve [1].

Considering that Bayu Field still has adequate remaining reserves [1], then it is determined that a strategy to reactivate shut-in wells was needed to increase oil production at field scale, as a mean to achieve their target of daily production rate. The goals of this study are to identify the problem source of shut-in (S/I) wells; to determine the operating procedure in handling the shut-in (S/I) wells; to identify the potential oil zones along with the perforation intervals, and conducted a reactivation strategy plan in Bayu field. In this study, Bayu-N3 well was chosen as one of the reactivation wells candidates to be implemented and evaluation.

2. Literature Review

Mature oil/gas field is defined as an oil and/or gas field which is in a state of declining production, or considered entering its final productive life cycle, nearing its economic limit values. According to Rukmana, D., et al., [2, 3] the characteristics of a mature oil/gas field are said to have current recovery factor greater than 30%, have been developed for more than 30 years, and to have more than 90% of water cut (WC). The determination whether a certain oil/gas field is considered mature or not could also be based from decline curve analysis results.

2.1. Reserve Estimation and Recovery Factor

Reserves is defined as an estimation of obtainable hydrocarbon amount in place, utilizing currently available technology, conforming with field conditions. Recoverable reserve is defined as obtainable hydrocarbon amount in place using period correct technologies [4]. Subsurface reserve estimation accuracy is paramount for field development planning which further used for cash flow projection to understand whether the said oil/gas field is considered feasible or not feasible to be further developed [5].

Reserve estimation using decline curve method is based on production history data. This method can only be used when a certain oil/gas field have already been produced, and with a declining profile. Reserve estimation is carried out with plotting production rate versus production duration [6, 7].

Recovery factor is defined as an amount that shows a ratio between producible hydrocarbon versus original hydrocarbon in place. The amount of recovery factor could be determined using J. J. Arps method, which based on the drive mechanism that currently in-play in the reservoir [2, 4, 6]; special core analysis (SCAL) results based on the correlation between relative permeability versus water saturation [2]; and based on fractional flow curve versus water saturation [3].

2.2. High Water Cut Analysis

Excessive produced water is the main cause of a well productivity decline. The increasing water cut impairs the inflow and outflow curve; and fluid lifting, treatment and handling, and disposal costs also increases. Excessive water production can be caused by well problems (mechanical problems), or other problems related to reservoir flow, such as water channeling or water coning [2, 3, 5, 8]. According to Chan, K. S. [9] and Sukubo, I, et al. [8]; water coning, multi-layer channeling, and borehole peripheral problems are the three main cause of excessive water production.

According to Allen, T. O., and Robert, A. P., [10], coning is defined as a production-related problem which renders the water below the production zone flows through via perforation zones around the borehole, therefore reduces oil production. Coning could appear when the oil production rate exceeds the fluid critical rate where coning could happen, stupendous drawdown pressure (exceeds the buoyancy force which inflicted in oil phase separated from gas and water phase), and exorbitant vertical permeability. Wojtanowicz, et al., [11], and Allen, T. O., and Robert, A. P., [10], mentioned that there are 7 parameters that affects water coning occurrence, such as mobility ratio, oil zone thickness, ratio of gravity and viscous force, well spacing, ratio of vertical and horizontal permeability, perforation interval, and well production rate.

Channeling is defined as an event where formation water from high pressured zones seeps upwards to oil production zone with lower pressure, then enters the wellbore via surrounding mini-channels. Those channels could be in the form of fractures (fracture channeling), oversized horizontal permeability due to rock heterogeneity known as multi-layered channeling [10], and due to poor cement bond between casing and formation [3].

In diagnosing and evaluating water coning and water channeling mechanism, we use several graphs that comprised from production history data. Chan, K. S. [9] successfully discovered coning and channeling phenomenon by using production history data. In identifying and evaluating on how coning and channeling could occur, Chan used WOR and WOR derivative (WOR') graph, and further obtained several graphs, known as Chan's Diagnostic Plot, for analysing bottom water coning, multi-layered channeling, rapid channeling, near-wellbore water channeling, and normal displacement.

2.3. Cement Log Analysis and Interpretation

Cement integrity logging is carried out to determine the quality and to evaluate cement bond between the back of casing and formation. Poor cement bond allows unwanted fluids entering the wellbore. Poor cementing jobs leave channels at the back of casing which allows unwanted fluids (e.g., gas or water) flow into the wellbore [12]. Cement integrity logs are categorized into 4 types [2, 12, 13], which are Cement Bond Logs (CBL), Cement Mapping Tools (CMT), Ultrasonic Cement Evaluation Tools (CET), and Ultrasonic Imagery Tools (USIT).

Crain, R., [14], described the utilization of acoustic amplitude curves to show cement bond integrity, whereas cement bond logs (CBL) described lower amplitudes indicate a good bonding index. Bond index is a qualitative indicator of channeling occurrences inside cement column. Crain's research [14] acquired charts to measure cement attenuation and compressive strength, and a graph of cement requirement versus casing size.

Variable density display logs (VDL) require precision in analyzing. VDL analysis are made by alternating sonic waves on each level of depths to a series of white-grey-and-black strips which represents amplitude of each peak and valley of sonic waves. Zero value of amplitude is marked by grey colors, negative amplitude is marked by white, and positive amplitude is marked by blacks [14]. Dwight K. S., [15], did a CBL-VDL analysis based on observing response comparisons which recorded on differing situations; namely on uncemented condition (Free Pipe), good casing to formation bond (Well Bonded), good to casing-poor to formation bonds, channeling, and micro-annulus. Suau, J., and Gartner, J., [13]; and Schlumberger [16] stated that USIT (Ultrasonic Imagery Tool) is one of logging devices used for evaluating cement quality and casing condition. In evaluating cementation practices, there are 2 (two) methods that are frequently used, namely are sonic wave method and ultrasonic wave method.

Hayman, et al., [17, 18], did a laboratory test of USIT capabilities in detecting micro-annulus and channeling, using a theoretical modelling. USIT would measure cement impedance values to discover channeling existence. Cement with a good quality would give out high impedance readings; and vice versa, cement with channeling existence would give out low impedance readings, if not zero. From the test results, it is also known that cement impedance values would rise in line with the more time it takes for cement to harden. Hayman, et al., [17, 18], also did an interpretation with showing USIT measurement results in the form of colorized chart logs with several columns exhibit measurement results; namely cementation evaluation results, casing corrosion evaluation, and a combination of both. The interpretation by Hayman, et al., [17, 18] and Schlumberger, [16], it is determined that the cement bond category in each condition is described as follows; good cement, channeling, false channels caused by casing wear and grooves, gas problem, micro-debonding (dry micro-annulus), and galaxy patterns as an indication of dual casing.

2.4. C/O Log Analysis and Interpretation

C/O Log is one logging method which purpose is to obtain oil saturation values and water saturation values at present time. In C/O Logs, gas saturation can also be measured separately with sigma or neutron porosity measurements. Oil saturation values measured from C/O Logs required correction or to be combined with other separate methods in measuring gas saturation [3, 19−22].

Eyvazzadeh, R. Y., et al., [23], also explained about how C/O logs work, which are said to use high-energy neutron generator, that are emitted to the formation. Neutron emissions collide, and yield 3 (three) processes; namely are inelastic collision, elastic collision, and absorption. Inelastic spectrums yield carbon and oxygen which are used to calculate hydrocarbon volume.

2.5. Economic Analysis

According to Partowidagdo, W., [24] and Herianto, [25], economic calculations are required to be implemented, regarding exploration activities and oil-and-gas exploitation is a capital-intensive, technologically-advanced, and high-risk industry; that it requires meticulous calculation to find out its profit and other economic parameters. Principally, economic calculation on exploitation and production of oil-and-gas resources depends on the amount of hydrocarbon that would be produced, costs that have been and/or will be incurred, oil-and-gas prices per unit of volume, and economic calculation systems that are currently in use.

Partowidagdo, W., [24] and Newendorp, P. D., [26] also explained that cash flow analysis and calculation will be preceded by knowing the regulations and profit-sharing contract that will be used for calculation. Elements that are required in calculation of Contractor Cash Flow are as such; gross revenues, investment, operating costs (OPEX), escalation rate, revenue share, taxable income, taxes, net contractor take (NCT), and government take.

Allison, G., [27], Partowidagdo, W., [24] and Herianto [25] explained that to understand whether a field development activity would give out a profitable value or not, it is imperative to carry out an economic analysis which use an economic valuation standard in petroleum industry by using economic indicators as such; Net Present Value, Rate of Return, Profit-to-Investment Ratio, Discounted Profit-to-Investment Ratio, and Pay-out Time.

The decision-making judgement is based on a sensitivity analysis from a risk-management analysis [26, 27]. Sensitivity analysis is defined as an analysis to perceive impacts of parameter changes which affects profit, such as oil prices, the amount of oil production, operational costs, and investment. The advantage of sensitivity analysis is that it aids on identifying the parameters that would affect profit by noticing on how much a profit would fluctuate from those parameter changes. An oil field would still be feasible to be developed, if it is projected to give out a relatively minute pay-out time (POT), a grand and positive net present value (NPV), a relatively substantial profit-to-investment ratio (PIR) and discounted profit-to-investment ratio (DPIR), and a rate of return value (ROR) that is far greater than bank interest [24, 25, 27].

3. Methodology

The methodology on this study is intended to solve the problems that are occurring at Bayu Field, especially on Bayu-N3 well; which comprised of data compilation and preparation, succeeded by data analysis and evaluation. The steps that are taken in this study are as follows:

a) Data collecting and preparation, includes geological data, reservoir data, and well data.
b) Conducted screening of well candidates for reactivation.
c) Analysis and evaluation of Bayu-N3 well data.
d) Identify and analyze the high water cut problem at Bayu-N3 well.
e) Identify and determination of oil and water zone, oil potential zone, and perforation intervals at Bayu-N3 well.
f) Economic analysis by observing economic indicators (NPV, POT, and IRR), and sensitivity analysis.
g) Give recommendation for reactivation strategy to be implemented in Bayu-N3 well.

Flowchart of the methodology on the evaluation and reactivation strategy in Bayu field is shown in Figure 1.

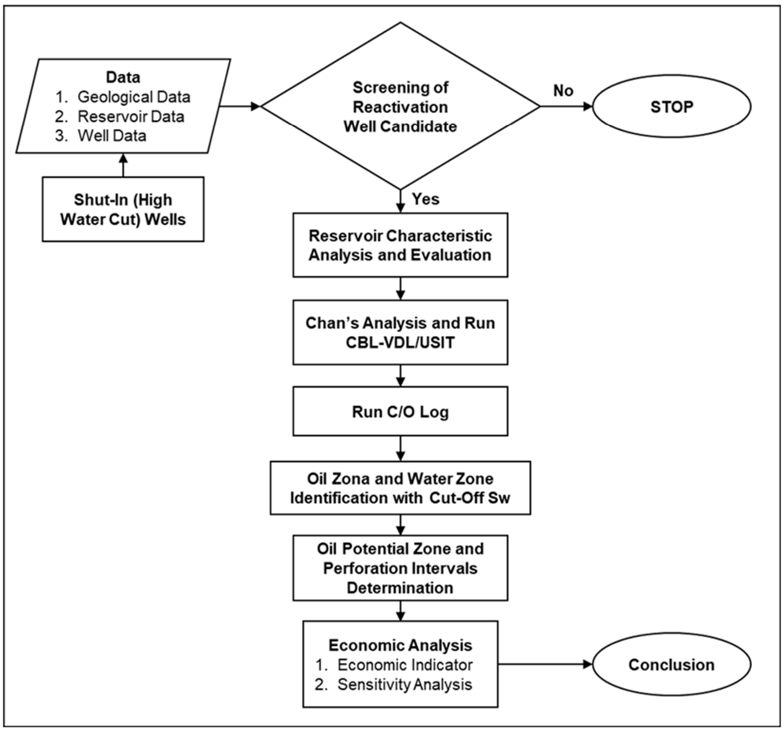


Figure 1. *Flowchart of the methodology.*

4. Results and Discussion

4.1. Screening of Reactivation Well Candidate

To ensure that we get the best candidate of well reactivation, first we need to make a screening of existing wells. One of the bases of consideration in deciding which well would be reactivated is the recovery factor (RF) value, in which the recovery factor of each well must be lower than the recovery factor based on SCAL data [3]. Result of the recovery factor determination from SCAL is shown in Figure 2. Based on the screening results which comprised of last production data (oil rate and water cut), well status, recovery factor on well basis [6, 7], and rock characteristics, we got 10 (ten) well candidates. Results of reserve estimation, and the recovery factor on a well basis for well reactivation is shown in Table 1.

Furthermore, based on the screening criteria in Table 1, we could determine well candidate priority based on recovery factor values on a well basis referred to Rukmana, D, et al. [3]. In this study, the early candidate for reactivation is Bayu-N3 well. The decision on choosing Bayu-N3 well as a candidate is due to it still has low current recovery factor (RF) with a value of 5.3%; compared to other candidates, and 52.99% of recovery factor based on SCAL data. Results of reserve estimation and recovery factor well basis of Bayu-N3 which will be reactivated is shown in Figure 3.

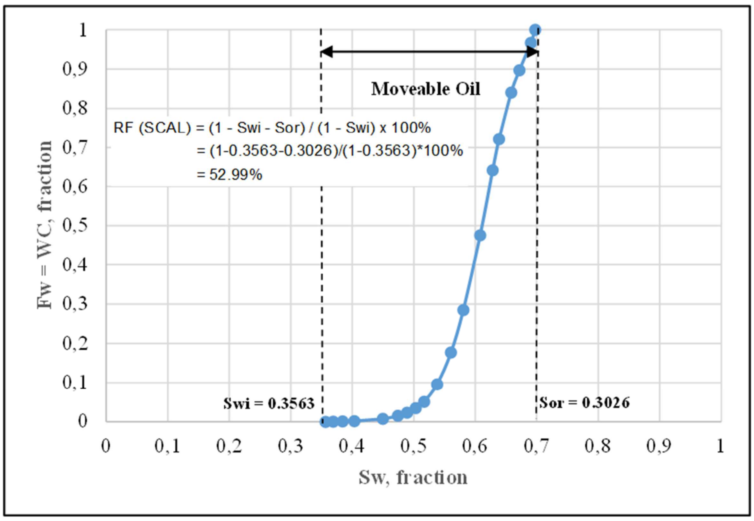
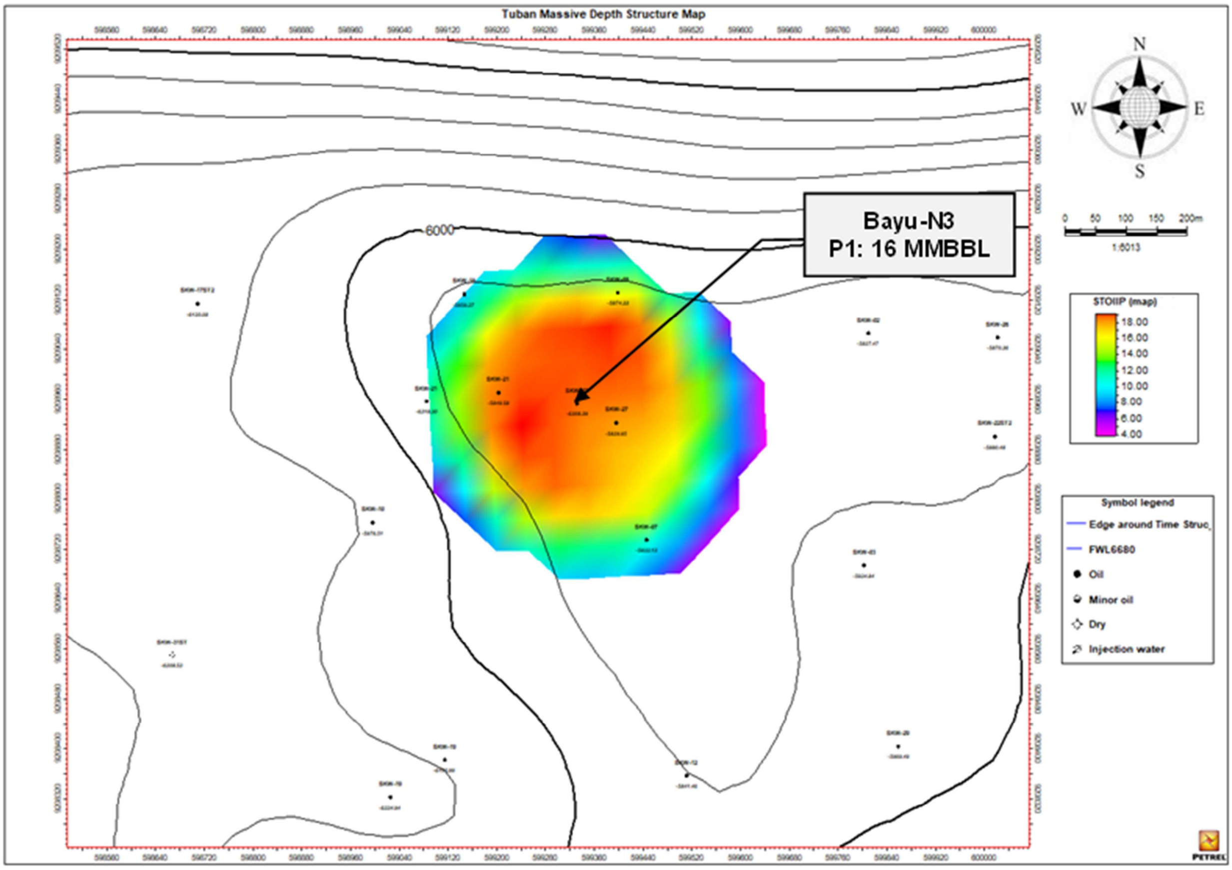


Figure 2. *Fractional flow curve determination of Bayu field from SCAL.*



Case	Bulk volume (*10^6 ft3)	Net volume (*10^6 ft3)	Pore volume (*10^6 ft3)	HCPV (*10^6 ft3)	STOIIP (MMBBL)	Prod. Cum. (MMBBL)	Remaining Reserve (MMBBL)	RF (%)
1P	2051	778	167	144	16	0.85	15.1	5.3

Figure 3. *OOIP dan RF well basis of Bayu-N3.*

4.2. High Water Cut Identification and Analysis

The shut-in wells found in Bayu Field have a common and major problem which is excessive amount of produced water, then causing a high water cut. Before reactivation strategy plan for Bayu-N3 well is started, we need to analyze the cause of the high water cut occurrence. This analysis is done by using Chan's diagnostic plot [9], where it shows a correlation between WOR and WOR derivative (WOR') versus cumulative production time. Later on, from Chan's diagnostic plot analysis [9], we can discover whether the cause of high-water cut is from coning or channeling existence. Based on Chan's diagnostic plot analysis on Bayu-N3 well, it is found that the cause of high-water cut occurrence is from channeling existence inside the well. Diagnostic plot result for Bayu-N3 well is shown in Figure 4.

Table 1. *Screening criterion results of well candidates for reactivation plan.*

No	Well	Existing Production			RF (%)	Problem (s)
		Oil (BOPD)	WC (%)	Last Produced		
1	Bayu-N1	96	93	S/I (Jan 2018)	24.3	Total loss at 7925-8250 ft MD
2	Bayu-N2	84	92	S/I (Oct 2017)	12.7	No Loss
3	Bayu-N3	97	100	S/I (Nov 2017)	5.3	Total loss at 6708-6909 ft MD
4	Bayu-N4	259	92	S/I (Mar 2019)	50.5	Total loss at 6940-7510 ft MD
5	Bayu-N5	78	97	S/I (Feb 2016)	31.8	Partial loss 6588-6642 ft MD; Total Loss at 6643-6677 ft MD, and 6736-6739 ft MD
6	Bayu-N6	5	100	S/I (Jun 2016)	51.3	Total loss at 6379 ft MD, 6518 ft MD, 6609 ft MD, 6681 ft MD, and 6744 ft MD
7	Bayu-N7	84	90	S/I (Mar 2018)	36.3	Total loss at 6584 ft MD
8	Bayu-N8	21	68	S/I (Dec 2017)	48,9	Partial loss at 7200 ft MD
9	Bayu-N9	0	100	S/I (Aug 2017)	38.3	Total loss at 9165 ft MD
10	Bayu-N10	16	55	S/I (Oct 2017)	39.7	Total loss at 7320-7341 ft MD, and 7512-7975 ft MD

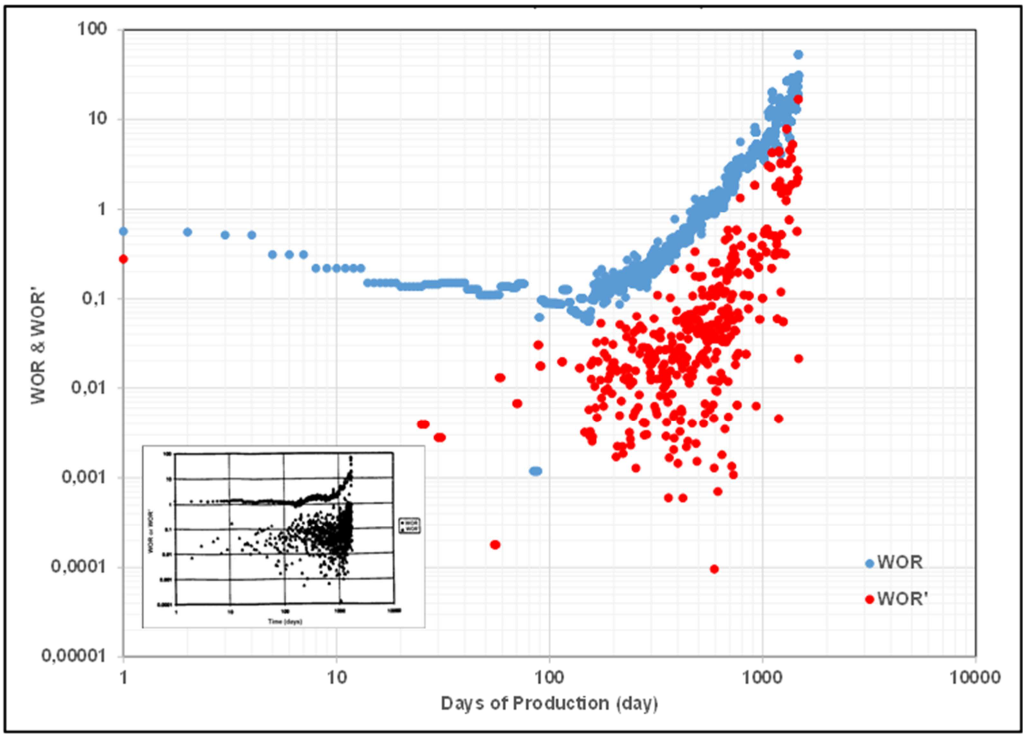


Figure 4. *Chan's diagnostic plot result of Bayu-N3 well.*

On the diagnostic plot of Figure 4, it is shown that when the early production time, we had a relatively constant value of WOR. Then, as the time goes by, WOR trendline started to rise rapidly and formed a linear slope as an effect of water breakthrough. WOR' curve trendline also showed a positive slope which indicated channeling existence at that perforation interval, this phenomenon is match with Chan's diagnostic plot curve [9]. To ensure the exact cause of channeling in each well, further we need to do a validation to the cement bond data and cement evaluation logs to discover whether the excessive amount of produced water was caused by poor cement bonds or was it caused by high water saturation at the perforation interval.

4.3. Cement Bond Evaluation

Based on the diagnostic plot result, Bayu-N3 well has a water channeling problem. To validate the condition, CBL-VDL [13−15] and USIT [17, 18] analyses were conducted. The CBL-VDL of Bayu-N3 well before remedial cementing is shown in Figure 5, and the USIT image Bayu-N3 well before remedial cementing is shown in Figure 6.

Based on CBL-VDL in Figure 5, CBL reading along with the production casing and at the existing perforation intervals (6642-6680 ft-MD) is higher than 50 mV, showing free pipe condition. The free pipe is a condition where there is no cement behind the casing so the annulus between the casing and the formation is not well-isolated. Column 3 (VDL reading) shows that at the early phase, the amplitude curve has a high casing arrival value. It also means that there is no cement behind the casing. At the late phase, the amplitude curve has scatter-high formation arrival which indicates that the VDL reading already reaches the formation.

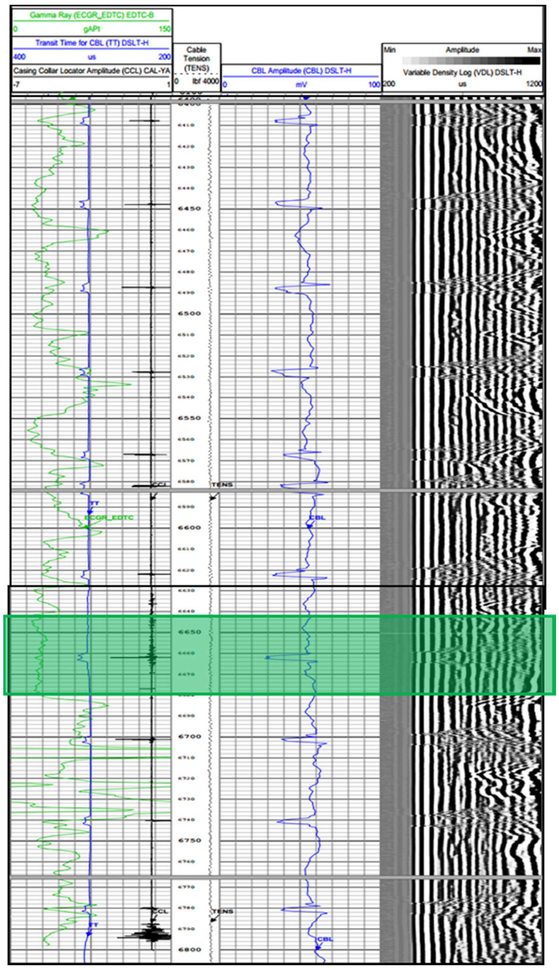


Figure 5. *CBL and VDL logs of Bayu-N3 before remedial cementing.*

Based on Figure 6, the USIT reading shows low cement impedance at column 5. The lower cement impedance reading, the poor cement quality behind the casing. Column 4 as the interpretation result of cement impedance shows that there is no cement behind the casing. Column 7 shows the fluid presence behind the casing. USIT result shows that there is only liquid that fills the annulus behind the casing. These conditions are strong validation to Chan's diagnostic plot analysis that the water channeling problem in Bayu-N3 well is caused by poor cement bonding that allows water from the water-bearing zone to flow into the wellbore through the cement channels. To fix this problem, remedial cementing is required.

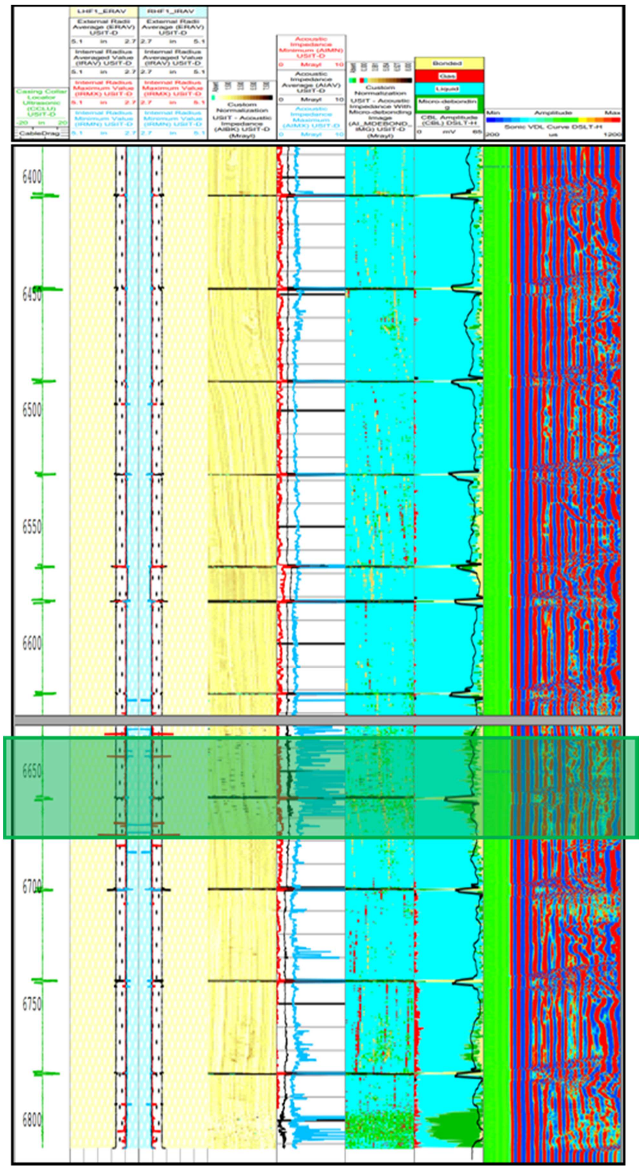


Figure 6. *USIT log of Bayu-N3 before remedial cementing.*

After the remedial cementing, CBL-VDL and USIT were run to see the cement condition behind the casing. Figure 7 shows the CBL-VDL reading after the remedial cementing. Column 3 shows cement bonding improvement at intervals 6550-6710 ft-MD. The CBL value at the intervals is less than 10 mV, indicating good cement bonding. Colum 4 as the VDL reading also shows low casing arrival amplitude and high formation arrival amplitude. That means that the casing already has good bonding with the cement at the same interval.

Furthermore, the USIT result is shown in Figure 8. From the USIT image we can see that there is cement bonding improvement at intervals 6550-6710 ft-MD. Column 5 shows the high cement impedance reading so the cement interpretation results at column 4 show the dark image. That result indicates that there is cement bonding improvement behind the casing. Column 7 shows that still there is liquid behind the casing by the blue color. Besides the liquid presence, there is an indication of micro-debonding that can ruin the cement bonding strength. Colum 6 as the interpretation result of column 7 imaging the condition behind the casing where there is micro- debonding at intervals 6620-6670 ft-MD. Besides, the liquid that fills the annulus behind the casing can lead to channeling. Moreover, the cement bonding condition at the top and bottom interval at 6550 ft-MD and 6710 ft-MD is bad, where there will be a chance for water channeling at those intervals.

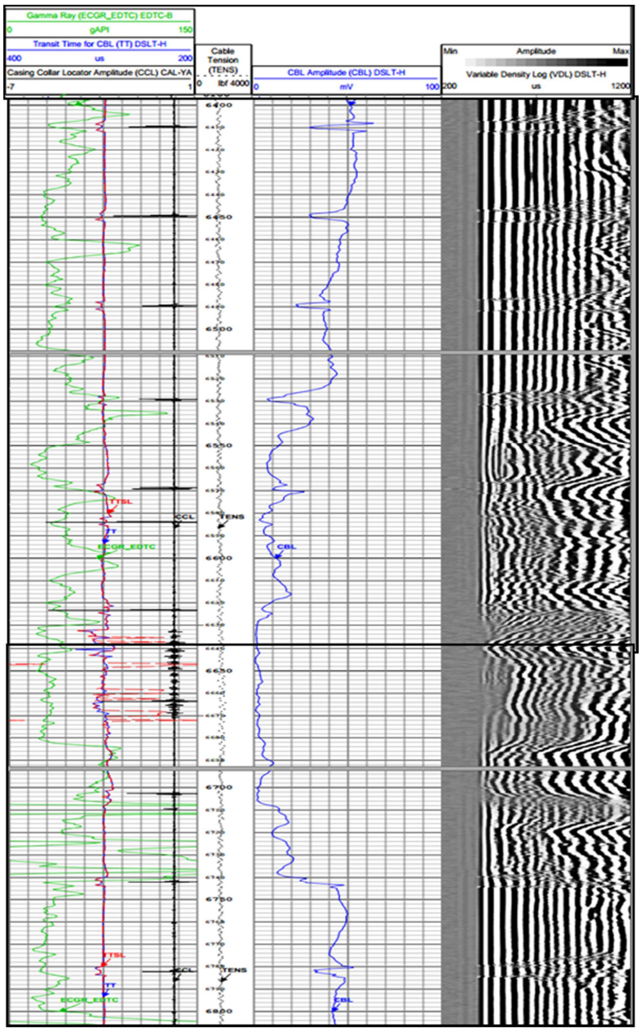


Figure 7. *CBL and VDL logs of Bayu-N3 after remedial cementing.*

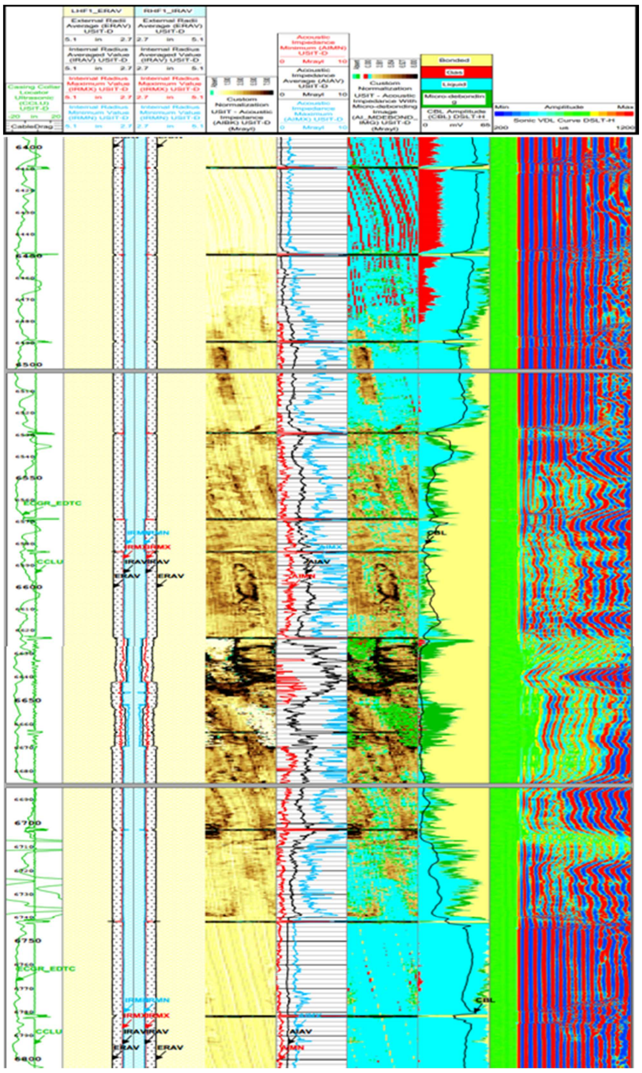


Figure 8. *USIT log of Bayu-N3 after remedial cementing.*

4.4. Carbon/Oxygen (C/O) Log Analysis Results

Carbon-Oxygen (C/O) log is one of saturation logging tools which purpose is to measure fluid saturation in producing wells, at present time [19−22]. From C/O log results, which water saturation (Sw) cut-off with certain value have already been applied [3], we can determine which layer or interval that had already been dominated with water and still contains moveable oil (So) that can be produced.

The remedial cementing job is further continued with running C/O log to evaluate current fluid saturation. Based from C/O log results, an analysis to discover which zones still contain producible oil, and which zones that have already saturated with water. Oil potential zones analysis is carried out by applying a cut-off on C/O log readings, with Sw cut-off value of 0.7 or 70%. This value shows when water saturation (Sw) value reached 70%, water cut (WC) value hit the 100% mark; but if the water saturation (Sw) value reached less than 70%, it still has movable oil saturation that can be produced. C/O log on Bayu-N3 was ran at the interval of 6400-6840 ft MD. To obtain information regarding which zones that are dominated with water and which zones that still have movable oil saturation (So), is analyzed with C/O log interpretation results that have been cut-off with water saturation (Sw) value. Interpretation results of C/O log for Bayu-N3 well that have been cut-off with 70% Sw value is seen in Figure 9.

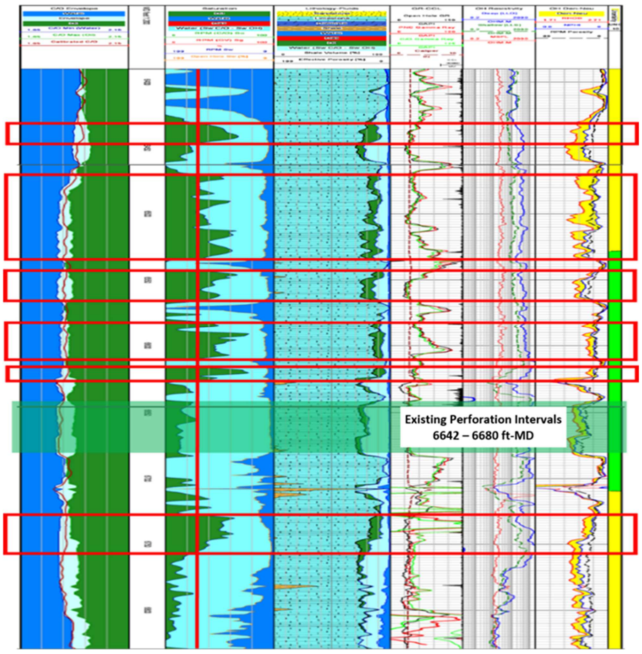


Figure 9. *C/O log interpretation result of Bayu-N3 well.*

Previously in Bayu-N3 perforation is opened at interval 6642-6680 ft MD [1]. It is visible from interpretation results that the interval of 6642-6680 ft MD has already saturated with water, as the Sw value at that interval had already reached 70%. Other than that, there are also total losses at the interval of 6706 ft MD. Water-saturated zones and the existence of total losses below perforation interval turned out to be one of the culprits behind the excessive water production of Bayu-N3. Hence, the idea is to open new perforation intervals that still contain oil potential. The results of oil potential zones analysis of Bayu-N3 are shown in Table 2.

Table 2. *The oil potential zones analysis result of Bayu-N3.*

No	Interval, ft MD	Analysis Results
1	6430-6450	Good So (40-65%), good porosity (15-25%)
2	6469-6534	Good So (30-60%), good porosity (10-25%)
3	6544-6564	Good So (30-60%), good porosity (20-25%)
4	6581-6610	Good So (40-70%), poor porosity (10-15%)
5	6618-6630	Good So (30-70%), *losses at* 6630 ft MD
6	6720-6761	Good So (30-60%), good porosity (15-30%)

4.5. Well Reactivation Strategy Planning

One of the production optimization efforts in the Bayu field is by reactivating the shut-in wells. The reactivation strategy was implemented on Bayu-N3 well after going through a comprehensive screening process. First, remedial cementing is done to fix the cement bonding quality between the production casing and the formation. Then, the C/O log is run to determine the potential oil zones with high current moveable oil saturation (So). Once the potential oil zone is determined, a perforation is done at the selected intervals to improve the oil recovery of Bayu-N3 well. From the C/O log evaluation at Bayu-N3 well, there are six potential oil zones. An integrated analysis of the C/O log interpretation result with the CBL/VDL and USIT interpretation result is done to select the perforation intervals candidate. The evaluation result is shown in Table 3.

There are two candidates of new perforation intervals: 6544-6564 ft-MD and 6581-6610 ft-MD. Both intervals have similar water saturation and cement bonding quality, but the interval 6581-6610 ft-MD is a tight reservoir. Interval 6430-6450 ft-MD and 6469-6534 ft-MD show the free pipe condition. Interval 6618-6630 ft-MD is also not a good candidate since there was a total loss at the interval. Meanwhile, interval 6720-6761 ft-MD shows the free pipe condition that could lead to water channeling.

Production perforation is carried out at interval of 6544-6564 ft MD, seeing that the oil saturation and porosity considered as good enough as shown in Table 3. From that interval, produce 1602 BOPD of oil rate (after reactivation) and 0% of water cut, as shown in Figure 10. This presented that the remedial cementing job is successful, as it reduced water production and increases oil production in Bayu-N3 well.

Table 3. *C/O log and CBL-USIT evaluation results of Bayu-N3 well.*

No	Interval, ft MD	C/O Log Evaluation	CBL-USIT Evaluation
1	6430-6450	Good So (40-65%), good porosity (15-25%)	CBL value > 40 mV, which depicts free pipe.
2	6469-6534	Good So (30-60%), good porosity (10-25%)	CBL value > 30 mV, which depicts free pipe.
3	6544-6564	Good So (30-60%), good porosity (20-25%)	CBL value ranged from 10-15 mV, USIT showed that cement poorly filled in casing annulus, micro-debonding existed and liquid fills in casing annulus.
4	6581-6610	Good So (40-70%), poor porosity (10-15%)	CBL value ranged from 1-15 mV, USIT showed that cement fills in casing annulus, but micro-debonding still exist which potentially cause micro-channelling.
5	6618-6630	Good So (30-70%), *losses at* 6630 ft MD	CBL value ranged from 1-20 mV, USIT showed that cement sealed between casing back and formation, but micro-debonding still exist which potentially cause micro-channelling.
6	6720-6761	Good So (30-60%), good porosity (15-30%)	CBL value ranged from 10-50 mV, USIT showed that cement poorly sealed casing and formation, and annulus was filled with fluids, which potentially cause channelling

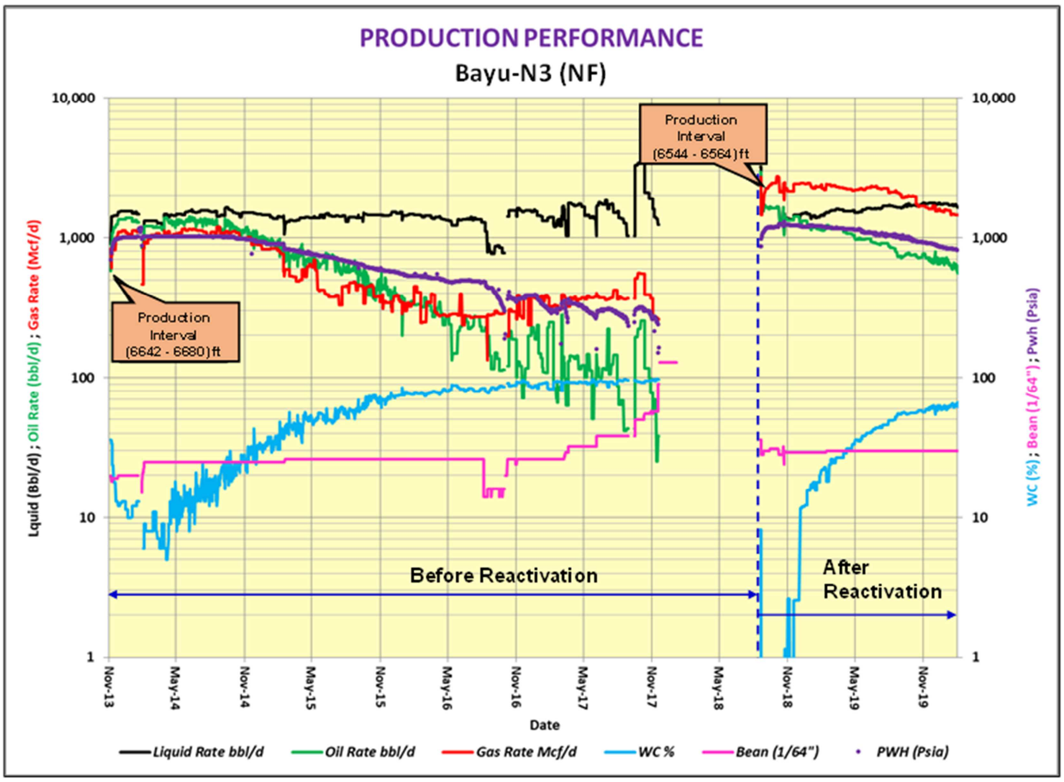


Figure 10. *Production performance of Bayu-N3 before and after reactivation.*

4.6. Economic and Sensitivity Analysis

Aside from technical standpoint, economic analysis is also taken into consideration as an evaluation of a study, by observing economic indicators such as NPV, POT, IRR, and PI [24, 25, 27]. Economic analysis will be carried out using PSC contract [1] on a well basis to observe the success rate of a reactivation activity for Bayu-N3 well. Data that will be used in economic analysis is shown in Table 4.

Table 4. *Data of economic calculation.*

Data	Value		Description
Project Lifetime	12	months	
Decline Rate	40	%/year	Ministry of Energy and Mineral
Oil Price (ICP)	36,68	USD/bbl	Resources Decree No. 134/2020
OPEX	8,44	USD/bbl	

Economic calculation result for Bayu-N3 well is shown in Table 5. It is show that Bayu-N3 well has an investment value of US$ 958,000 with obtained gain of 1602 BOPD. From the calculation results, obtained an NPV value of US$ 5,153,000 in the project life of a year. Time needed to return the amount of investment (Pay Out Time/POT) is in the 0.16 years or 1 month and 29 days.

Table 5. *Economic calculation results for Bayu-N3 well.*

Parameters	Unit	Amount
Total Gross Revenue	US $ (000)	17,977
OPEX and Depreciation	US $ (000)	5,094
Contractor Take	US $ (000)	5,153
Government Take	US $ (000)	7,730
NPV (DF 10%)	US $ (000)	5,153
IRR	%	538.0
POT	Years	0.16
PI	US$ / US$	6.38

Sensitivity analysis is defined as an analysis that carried out to observe the effects of parameter changes that will affect profit, seen from its economic indicator results [24, 27]. Parameters used for executing sensitivity analysis are cumulative oil production, oil prices, amount of investment, and lifting costs [1, 24, 27]. This analysis is carried out by changing prices against sensitivity values, with decline as much as 10%, 20%, and 30%; and increase as much as 10%, 20%, and 30% each. The results of sensitivity analysis are plotted into a spider diagram, then observing its sensitivity to NPV values, IRR values, and duration of POT. Sensitivity spider diagrams of Bayu-N3 well are shown in Figure 11 through Figure 13.

Based on the Figure 11 through Figure 13, it is generally observed that the most affecting parameters to the economic indicators are oil prices and cumulative oil production, followed by lifting costs and investment values.

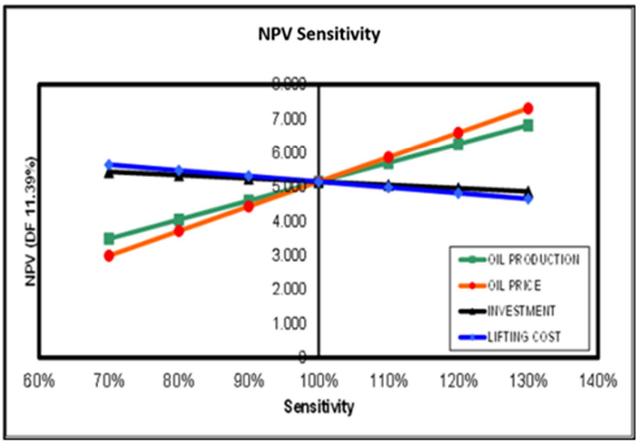


Figure 11. *Sensitivity analysis of net present value of Bayu-N3.*

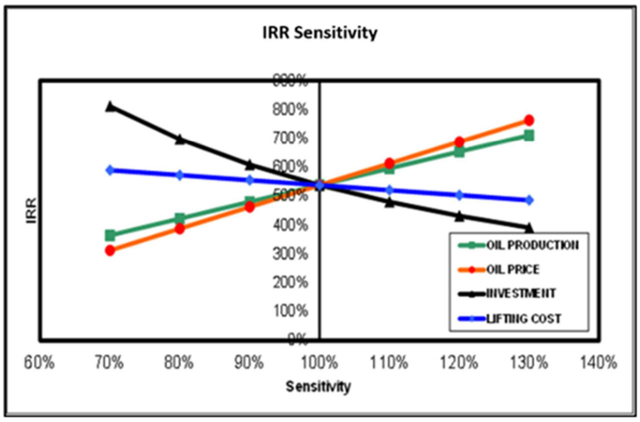


Figure 12. *Sensitivity analysis of rate of return of Bayu-N3.*

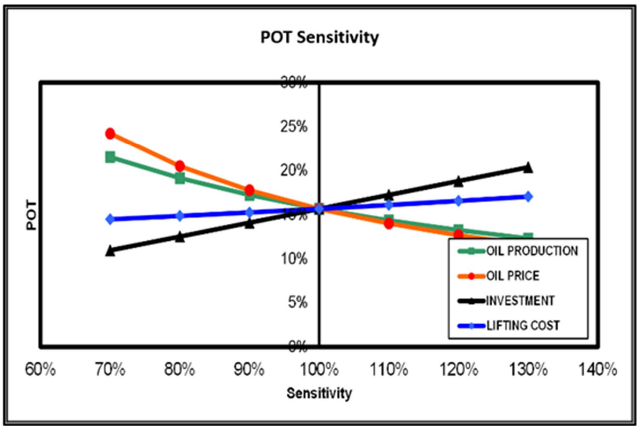


Figure 13. *Sensitivity analysis of pay out time of Bayu-N3.*

5. Conclusion

Based on the analysis and evaluation results, a conclusion can withdraw as follows:

1) Screening results by analyzing and evaluating oil saturation values (30-65%), porosity (10-25%), and recovery factor based on SCAL (RF=52.99%) stated that Bayu Field has 10 (ten) candidates of shut-in (S/I) wells and the first priority of well reactivation candidate is Bayu-N3 well (RF=5.3%).
2) Analysis results which integrate Chan's Diagnostic Plot and cement evaluation logs (CBL-VDL-USIT) stated that the cause of high water cut occurrence especially in Bayu-N3 well is channeling, which caused by free pipe condition where cement column didn't provide a good bond between the back of casing and the formation.
3) To overcome the existence of water channeling inside shut-in wells especially in Bayu-N3 well, remedial cementing job is required to remedy the cement bond quality; further validated by re-running cement evaluation logs (CBL-VDL-USIT).
4) Based on analysis and evaluation results of C/O log after remedial cementing job is done, it is observed that Bayu-N3 well still has 6 (six) oil potential zones which can be further developed, found at interval of 6430-6450 ft MD, 6469-6534 ft MD, 6544-6564 ft MD, 6581-6610

ft MD, 6618-6630 ft MD, and 6720-6761 ft MD.

5) The reactivation strategy to improve the oil production of Bayu-N3 well was executed by conducting a remedial cementing job and by perforating the potential oil zone obtained from C/O log analysis, which is done at interval 6544-6564 ft-MD and gives producing 1602 BOPD with 0% of water cut.
6) Based on economic analysis with observing economic indicators, shut-in well reactivation plan for Bayu-N3 well secured a sum of NPV in the amount of 5153 MUSD, 538% IRR, and POT is 1 month and 29 days.
7) Reactivation strategy of Bayu-N3 well is technically and economically able to improve oil production, and could be used as reference in implementation to other candidate wells in Bayu field.

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