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The Application of Remedial Cementing to Handle CO_2 Gas Channelling Problem: Case Study in D-04 Well of Jatibarang Field

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ABSTRACT - The study aims to identify solutions to declining oil production and frequent failures of the electrical submersible pump (ESP) and its cable in D-04 well caused by CO_2 gas channelling, as well as to evaluate the effectiveness of remedial cementing in addressing these issues. An integrated analysis was conducted through the implementation of Cement Bond Log (CBL) and Variable Density Log (VDL) to identify the problematic zones. The results were used to determine the necessity of re-cementing and zone-specific reformulation. In addition, well performance evaluation after cement bond improvement was evaluated by comparing production performance before and after remedial cementing. The analysis identified three zones requiring remedial cementing, located at intervals of 1040-1041 mMD, 1045-1048 mMD, and 1055-1057 mMD. The remedial cementing process was carried out in three stages: the first stage to seal the productive zone, the second stage to improve bonding in the CO_2 gas channelling zone, and the third stage to improve bonding in the water channelling zone. Based on CBL and VDL logs as well as well performance before and after remedial cementing, the results indicate that the overall bonding improvement in cement bonding successfully isolated gas and water zones, and had a positive impact on production performance, as evidenced by an increase in oil production cumulative from 1370 bbl to 1452 bbl.

Keywords: remedial cementing; channelling; CO_2 gas problem; reformulation.

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INTRODUCTION

The D-04 well is located in the working area of PT Pertamina EP, Jatibarang field West Java, Indonesia. The well has been producing since 2013; however, oil production has continued to decline, accompanied by frequent failures of the electrical submersible pump (ESP) and its cable due to downhole electrical problem, as shown in Figure 1. This condition indicates the presence of carbon dioxide (CO_2) gas channelling from the open formation, which is also produced along with fluids and infiltrates the ESP cable, causing damage. The resulting impacts include failures of the artificial lift system, decreased well productivity and frequent well interventions to replace the artificial lift system.

The initial primary cementing of D-04 well was unsuccessful in mitigating the CO_2 channelling problem. Cementing operations were conducted multiple times but failed to effectively seal the loss zones. Based on the analysis of the Cement Bonding Log (CBL) data, poor cement bonding conditions were identified within and around the target zones. CBL log data can be used to identify voids in the annulus between the casing and the formation, these voids must be repaired prior to perforation and production.

To address these issues, and as part of a workover management plan, remedial cementing (squeeze cementing) was carried out in the target zones as well as in the intervals above and below them to mitigate the CO_2 gas channelling. Consequently, it was necessary to reformulate the cement slurry design based on CBL evaluation results to ensure effective sealing of the identified zones.

The objectives of this study are to identify the root causes of artificial lift equipment failures (ESP and cables), to develop and implement an appropriate cement bond repair strategy, and to establish an effective remedial cementing approach for optimizing oil production in wells experiencing gas channelling in the Jatibarang Field. The results are expected to serve as a reference for handling CO_2 gas channelling in other wells. Furthermore, the novelty of this study lies in the integrated evaluation of well problems, reformulation of cement design, cement integrity, and production performance as part of reservoir management for future field development optimization.

The study began with the collection of data, including well data, reservoir data, logging data, and cementing programs. An analysis was then conducted to determine the causes of water/CO_2 gas channelling in D-04 well by interpreting the Cement Bond Log (CBL) and Variable Density Log (VDL). The analysis results were used to determine whether re-cementing and reformulation were required in specific zones to address the water/CO_2 gas channelling problem. Well performance evaluation was conducted after the

Figure 1. Damage on the ESP cable and bottom hole assembly of the D-04 well

bonding improvement by comparing production performance before and after the remedial cementing. The success of the remedial cementing in D-04 well can be seen from the results of the cement design reformulation, improvements in cement bonding to address the water/CO_2 gas channelling issue, and the increased well performance.

METHODOLOGY

Literature review

The risk of unintended CO_2 migration from the reservoir is minimized through careful site assessment and appropriate reservoir selection. However, if such migration occurs, remediation efforts are required, including active remediation methods (Zhang et al., 2016; Bernd et al., 2019). Sealing CO_2 migration pathways using cement and gels is considered a potentially long-lasting solution for small- to medium- scale leaks (Zhang et al., 2016). Cement provides a rigid matrix to fill voids, whereas gels can penetrate deeper into porous media but required structural support for effective sealing (Zhang et al., 2016; Bernd et al., 2019).

Cementing operations in oil and gas wells are among the most complex processes well completion (Nelson et al., 2006; Munoz et al., 2024). Cement is expected to provide structural support and zone isolation throughout the well lifecycle, including after abandonment (Navid et al., 2015). Among remedial techniques, squeeze cementing is the most commonly applied method in field operation due to its similarity to primary cementing and the availability of materials (Diaz et al., 2016). However, the slurry typically has lower viscosity compared to conventional cementing slurry (Navid et al., 2015).

Squeeze cementing can be defined as the process of pumping cement slurry into the wellbore under pressure so that it enters perforations or voids and seals the zones (Diaz et al., 2016). The applications include repairing primary cementing (Izadi et al., 2024), sealing lost circulation zones, fixing casing leaks (Doonechaly et al., 2024), closing incorrect perforations, isolating depleted zones (Permadi et al., 2010; Muskat et al., 2013; Li et al., 2020), mitigating stuck pipe issues during cement drill-out operations (Suranta et al., 2026). Squeeze cementing refers to the process of injecting cement slurry at pressurized conditions into the annulus or cracks generated in the wellbore cement system (Navid et al., 2015). The most common squeeze cementing method is the balanced plug technique, in which tubing or drill pipe is run to the desired depth and spacer fluids are used to prevent contamination between cement slurry and drilling mud (Portman et al., 2004; Rizky et al., 2022).

Weak formation encountered during drilling often requires special treatment, such as the use of a lightweight cement system to minimize lost circulation and formation damage (Brandl et al., 2011; Sauki et al., 2015; Praptiwi et al., 2020). Lightweight and ultra-lightweight cement formulations provide improved cement strength, better bonding and enhanced cement bond log response. These systems also enable deeper placement in wells (Ashena et al., 2014; Sarmah et al., 2016), although achieving optimal rheological properties and fluid loss control remains challenging (Saroyo 2014; Sauki et al., 2015).

Wireline logging is one of the primary methods for monitoring wellbore conditions. Tools such as Cement bond logs (CBL), variable density logs (VDL), ultrasonic casing imagers (UCI), and corrosion logs, are some widely recognized wireline logging instruments to check the current cement integrity condition based on basic downhole requirements CBL and VDL assessing the consistency of cement behind the casing, evaluating the separation between reservoir units (Ashena et al., 2014; Navid et al., 2015; Saimi et al., 2021; Suhascaryo, Kumara & Prasetyo., 2025). Acoustic energy loss measured by CBL is proportional to the fraction of casing perimeter protected by the cement. 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).

The success of squeeze cementing can be evaluated through well logging analysis (CBL and VDL) and production performance indicators such as oil rate and water cut (Fitrianti & Satria 2020; Saini et al., 2021). Good cement bonding is typically indicated by CBL reading value of less than 10 mV (Schlumberger 2015; Rukmana et al., 2020; Kristanto et al., 2026). This value is a standard set by SKK Migas as a guideline for evaluating cement bond strength in oil wells in Indonesia. If the CBL reading shows a value of more than 10 mV, some problems such as excessive water production or channelling around the well potentially occur. Thus, remedial cementing is required (Rukmana et al., 2020; Kristanto et al., 2026).

Methodology

In general, this study consists of several stages to evaluate the results of remedial cementing and cement slurry reformulation. The evaluation of remedial cementing success in addressing CO_2 gas channelling problems in the D-04 well, Jatibarang Field, is divided into 3 (three) stages:

- Analysis of CO_2 gas channelling problems through interpretion of Cement Bonding Log (CBL) and Variable Density Log (VDL).
- Implementation of remedial cementing and slurry reformulation in zones identified with poor cement bonding.
- Evaluation of well performance after cement bond repair to assess the of remedial cementing and reformulation.

The flowchart of the study is shows in Figure 2. The data preparation stage is a critical part of the analysis, as it directly affects the accuracy of the analysis results. The required data include reservoir data (petrophysical properties, PVT data, and reservoir thickness), well data (well depth, tubing length and diameter, and artificial lift system), operational data (workover, well intervention, and well service), logging data (CBL and VDL) and cementing program data (design and procedures).

According to Bernd et al., (2019), in developing cement slurry reformulation, several aspects must be considered:

- Health, safety, and environmental (HSE) considerations including the use of environmentally friendly materials.
- Chemical reactions must be controllable, and operational cleanliness must be realistically achievable using standard oilfield equipment.
- Sealant materials should be economically feasible.
- The formulation must be applicable under typical CO_2 reservoir conditions and possess sufficient flexibility.

RESULT AND DISCUSSION

Analysis of the causes of CO_2 gas channelling

The production perforation of D-04 well is located in the C1 layer at an interval of 1045-1048 mMD, corresponding 3.0 m of net pay. As of June 2024, the C1 layer has produced 0.5 MMSTB with remaining reserves of 1.5 MMSTB. The well exhibits a higher water cut (WC) of 92%, with a net oil production of 92 BOPD.

The first step taken was to analyze the causes of water/CO_2 gas channelling in D-04 well by interpreting the petrophysical logging data and the Cement Bond Log. Based on the log analysis (Figure 3), zones above the target interval (1040–1041 mMD) and below the target interval (1055–1057 mMD) show relatively low resistivity values, suggesting the presence of gas and water. Further analysis of the CBL log at these depths shows a bonding value of approximately 50 mV. The aforementioned value is classified as poor bonding (Schlumberger., 2015; Rukmana et al., 2020) and is associated with the occurrence of channelling problems. Channelling refers to small voids or channels between the casing and the formation, formed due to incomplete cementing. This condition causes fluid flow (such as gas or water) along narrow paths or channels formed within the cement, allowing water or gas to penetrate into the borehole and be produced.

Planning of cement bonding repair

To address the issue of damage to the Electric Submersible Pump (ESP) in D-04 well, re-cementing (squeeze cementing) was performed in the channelling zone and the target zone, which had poor cement bonding, specifically at depths of 1040-1041 mMD, 1045-1048 mMD, and 1055-1057 mMD.

The remedial cementing plan was carried out in three stages. The first stage was isolation of the production interval (1045-1048 mMD) using a cement plug, followed by re-drill. The second stage was improvement of cement bonding above the production zone through perforation and squeeze cementing at 1040-1041 mMD to mitigate gas channelling. The third stage was improvement of cement bonding below the production zone through perforation and squeeze cementing at 1055-1057 mMD to overcome the water zone channelling. The method used is the balance plug method, a cementing technique that involves placing cement plugs at specific intervals within the well, taking into account the strength of the casing and the formation's ability to withstand pressure to prevent fracturing during cement injection.

First stages: cement bonding repair in production zone

The first stage aimed to seal and improve cement bonding in the production interval (1045-1048 mMD). Prior to remediation, the interval showed CBL values of 20-30 mV, which are classified as moderate bonding (Schlumberger., 2015). The cementing design for this stage utilized a combination of 2-7/8" EUE tubing and 2-7/8" IF Drill Pipe, with the end of the string set at a depth of 1038 mMD. The upper reference (UR) was placed 2 m above the perforation zone due to loss circulation conditions. The first stage cementing operation was successfully completed after four attempts involving cementing and slurry reformulation design are presented in Table 1, while the well diagram of D-04 well in the first cementing stage is shown in Figure 4.

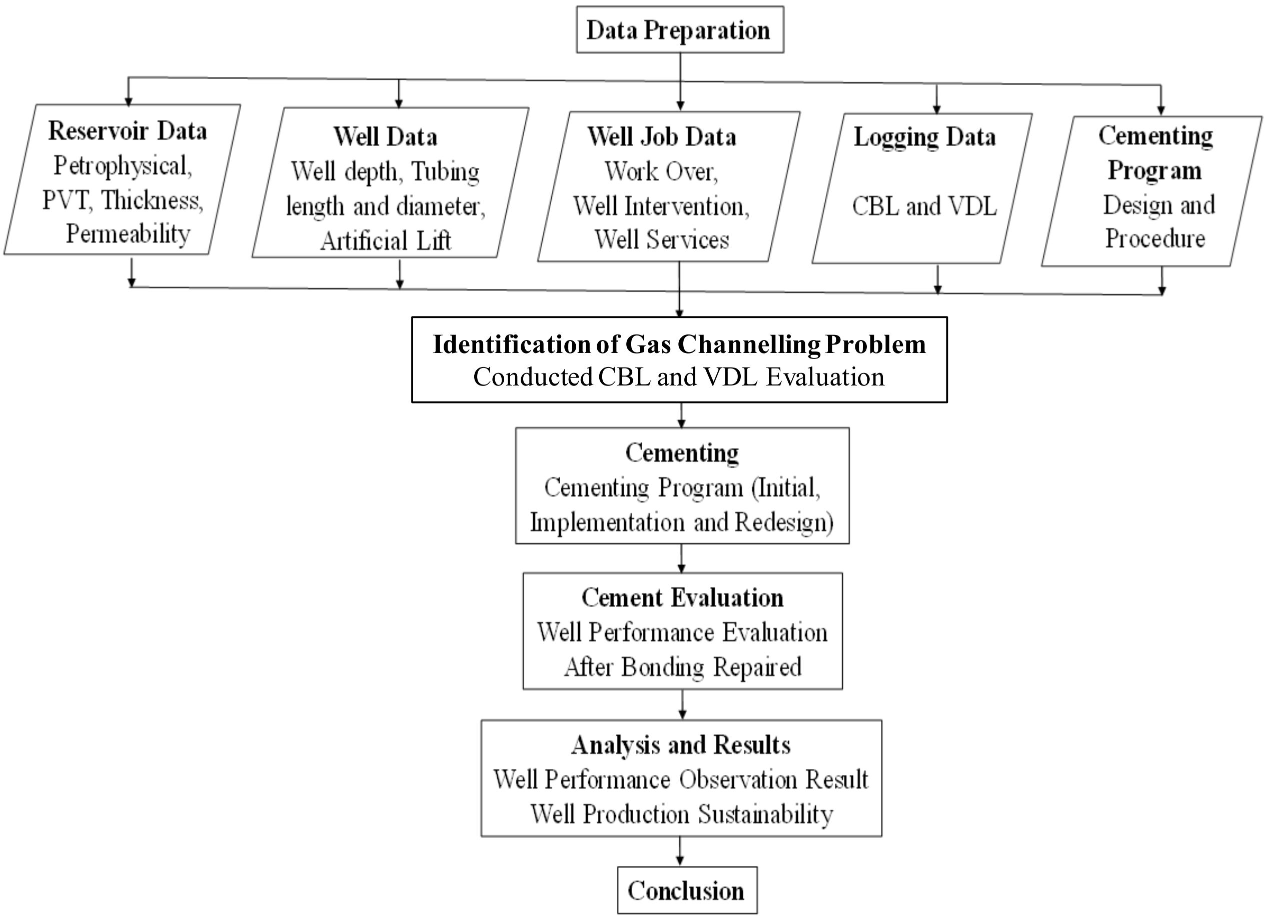

Figure 2. Flowchart of the study

Parameters calculation for first formulation design in Equation 1:

Casing Capacity 7”

$$\frac{volume\ (bbl)}{height\ (m)} = \frac{\pi}{4}\ x\ (d\ inch)^2 x\ \frac{1\ bbl}{9702\ inch^3}\ x\ \frac{1\ inch}{0.0254\ m} = \frac{\pi}{4}\ x\ (6.355\ inch)^2 x\ \frac{1\ bbl}{9702\ inch^3}\ x\ \frac{1\ inch}{0.0254\ m} = 0.1293\ bbl/m \quad (1)$$

Volume of cement slurry:

- Calculating the length of the inside casing cement volume
  = Set EO - target TOC
  = 1051 - 1027.8 mMD = 23.2 m
- Calculating the estimated squeeze length
  = target TOC - TOC String Out
  = 1027.8 - 989.1 m = 38.7 m
- Total length
  = 23.2 + 38.7 m = 61.9 m
- Calculating the volume of cement slurry
  = total length x 7" casing capacity
  = 61.9 m x 0.1293 bbl/m
  = 8 bbl

The first formulation design used a cement density of 15.8 ppg with a volume of 9 bbl. The thickening time in the first formulation was designed for 260 minutes; however, the cementing operation was unsuccessful, as no top of cement (TOC) was observed, indicating significant cement loss. Therefore, a second formulation was performed.

The second formulation maintained the same a density (15.8 ppg), but the cement slurry volume was increased to 31 bbl to compensate for losses. The thickening time was reduced to 215 minutes to accelerate the cement hardening process. Despite these adjustments, the operation remained unsuccessful, as no TOC was detected, indicating continued cement loss.

The third remedial cement bonding formulation design used a smaller density than the previous one of 12.8 ppg (light weight slurry) for loss formation with a cement slurry volume of 16 bbls to cover the loss. Thickening time was further shortened to 170 minutes to speed up the cement hardening process. This attempt successfully identified top of cement (TOC); however, the result was still not optimal. During the casing pressure test at 700 psi for 10 minutes, leakage was detected, indicating insufficient compressive strength. Therefore, further reformulation of cement slurry was required.

The fourth formulation used a density of 12.5 ppg (lightweight slurry) with a slurry volume of 16 bbl. Thickening time was reduced to 163 minutes. Additionally, spherelite material (lite cement) was added at 19.5% BWOC to improve compressive strength. This stage was successful: TOC was confirmed, and no leakage was observed during the casing pressure test at 700 psi for 10 minutes at a depth of 1048 mMD. Spherelite is a lightweight additive. It is used as an additive in drilling cement, resulting in a cement slurry with a lower specific gravity than standard cement, which is 15.86 ppg (Bernd et al., 2019).

Second and third Stages: cement bonding repair above and below the production zone

The second and third stages aimed to repair cement bonding above and below the production zone, specifically at 1040-1041 mMD and 1055-1057 mMD. Prior to remediation, both intervals showed CBL reading values of 50 mV, which are classified as poor bonding (Schlumberger., 2015; Rukmana et al., 2020). Details of the cementing formulations are presented in Table 2.

The second-stage cementing operation is targeted at the zone 1 m above the production zone (1040-1041 m) with the CBL reading of 50 mV to address gas channelling issues. Perforations were created using a wireline HSD Gun prior to squeeze cementing. The cementing operation utilized 2-7/8” EUE tubing and 2-7/8” IF drill pipe, with the string set at 1043 m and the UR positioned 2 m below the bonding perforations. The balanced plug method was applied. The slurry density was 15.8 ppg with a volume of 6 bbl, based on IRT results for tight formation. The thickening time was designed at 308 minutes to sufficient squeezing time.

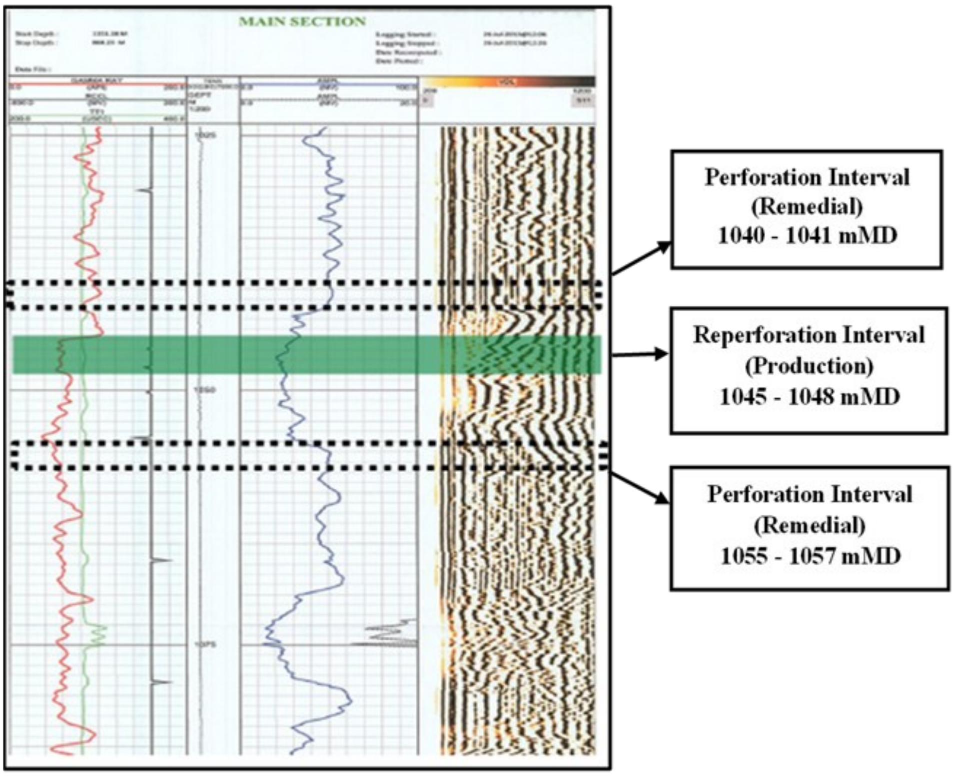

Figure 3. CBL of D-04 well before bonding repair

Table 1. Remedial cement bonding formulation design for the production zone

Properties	Unit	Design formulation			
		1	2	3	4
Density	ppg	15.8	15.8	12.8	12.5
Yield	cuft/sack	1.19	1.97	2.28	2.2
Mixing Water	gal/sack	3.71	3.75	8.1	7.32
Total Fluid	gal/sack	5.38	5.37	13.52	10.44
Cement Slurry Volume	bbl	8	30	15	15
Dead Volume	bbl	1	1	1	1
Total Slurry Volume	bbl	9	31	16	16
Cement Class G	sack	42	145	39	41
A-02 (activator)	%bwoc/pounds	0 / 0	0 / 0	5 / 183.3	1.00 / 38.5
SF-01 (Silica Flour)	%bwoc/pounds	0 / 0	0 / 0	0 / 0	0 / 0
Spherelite (Lite)	%bwoc/pounds	0 / 0	0 / 0	0 / 0	19.5 / 751.5
EXT-1L (Extender)	gps/gal	0 / 0	0 / 0	1 / 39.0	0.35 / 14.4
FR-1L (Fric Reducer)	gps/gal	0.14 / 5.9	0.10 / 14.5	0 / 0	0 / 0
FL-1L (FLC)	gps/gal	0.60 / 25.2	0.60 / 87	2.00 / 78.0	1.00 / 41.0
AMG-1 (AMG)	gps/gal	0.80 / 33.6	0.80 / 116	2.00 / 78.0	1.50 / 61.5
AF-1L (Defoamer)	gps/gal	0.08 / 3.4	0.08 / 11.6	0.08 / 3.1	0.08 / 3.3
R-1L (Retarder)	gps/gal	0.05 / 2.1	0.04 / 58	0.05 /2	0.12 / 4.9
Fresh Water	gps/gal	3.71 / 156	3.75 / 554.2	8.10 / 315.9	7.32 / 299.9
Gelling Agent	ppb/pounds	0 / 0	3.50 / 63	2.50 / 27.5	3.50 / 35

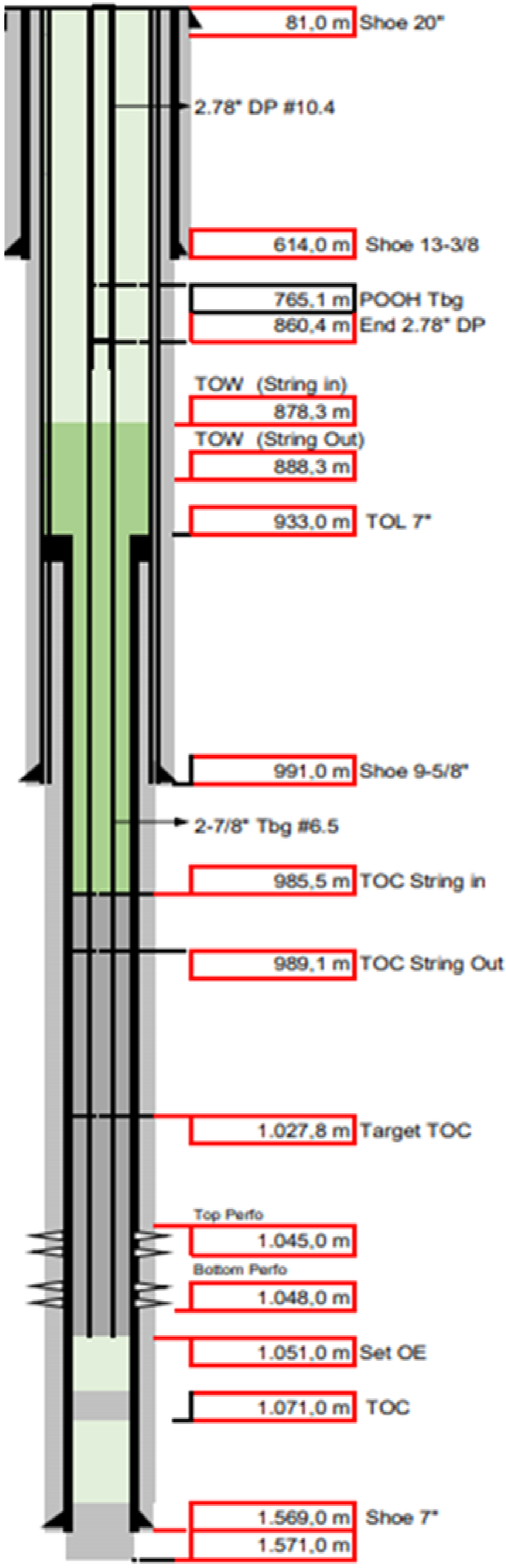

Figure 4. Well diagram of first stage cementation

The third stage targeted the interval 2 m below the production zone (1055-1057 mMD) with CBL reading of 50 mV to mitigate water channelling issues. Prior to performing squeeze cementing in this interval, perforations were made using a wireline HSD Gun. The cementing design utilized a combination of 2-7/8" EUE tubing and 2-7/8" IF drill pipe, with the string end positioned at 1038 mMD and the UR placed 4 m below the bonding perforation (at 1061 mMD). The cementing method employed remained the same as in the first and second stages: the balance plug method. The slurry density used in the formulation design for the third-stage cementing is 15.8 ppg with a volume of 8 bbl based on the IRT results for the tight formation. This is suitable for formations with low pressure, classified as weak formations, with a slurry density of 11-15.9 ppg (Sarmah et al., 2016). The second and third stages cementing were successful due to top of cement (TOC) was detected, and during the compressive strength test (casing pressure test) at 700 psi for 10 minutes, no leakage was found in that interval. It is also shows that the selection of slurry density is critical in maintaining the stability of the formation.

CBL data analysis after bonding repair

After bonding improvement was performed using remedial/(squeeze) cementing on D-04 well, CBL and VDL analyses were conducted following the bonding to determine whether the improvement was successful.

Figure 5 shows the CBL log after remedial cementing, indicating significant improvement in cement bonding. It is concluded that the three intervals where remedial cementing was performed showed improved bonding results. The amplitude of CBL log at interval 1040-1041 mMD (squeeze) decreased from 50 mV to 10 mV, at interval 1045-1048 mMD decreased from 30 mV to 5 mV. In the interval 1055-1057 mMD (squeeze) decreased from 50 mV to 10 mV. Observation of the CBL signal at these three intervals also shows better results. This result has been congruent that good cement condition in the context of evaluation using cement bond log is when the reading value is 10 mV or less (Schlumberger., 2015; Rukmana et al., 2020; Kristanto et al. 2026).

Table 2. Second and third stages cementing formulation design

Properties	Unit	2nd Stage (Gas Zone)	3th Stage (Water Zone)
Density	ppg	15.8	15.8
Yield	cuft/sack	1.19	1.19
Mixing Water	gal/sack	3.61	3.71
Total Fluid	gal/sack	5.38	5.38
Cement Slurry Volume	bbl	5	8
Dead Volume	bbl	1	1
Total Slurry Volume	bbl	6	9
Cement Class G	sack	28	42
A-02 (activator)	%bwoc/pounds	0 / 0	0 / 0
SF-01 (Silica Flour)	%bwoc/pounds	0 / 0	0 / 0
Spherelite (Cement Lite)	%bwoc/pounds	0 / 0	0 / 0
EXT-1L (Extender)	gps/gal	0 / 0	0 / 0
FR-1L (Friction Reducer)	gps/gal	0.18 / 5	0.14 / 5.9
FL-1L (Fluid Loss Control)	gps/gal	0.70 / 19.6	0.60 / 25.2
AMG-1 (Anti Migration Gas)	gps/gal	0.80 / 22.4	0.80 / 33.6
AF-1L (Defoamer)	gps/gal	0.08 / 2.2	0.08 / 3.4
R-1L (Med Temp. Retarder)	gps/gal	0.02 / 0.6	0.05 / 2.1
Fresh Water	gps/gal	3.61 / 101.1	3.71 / 156

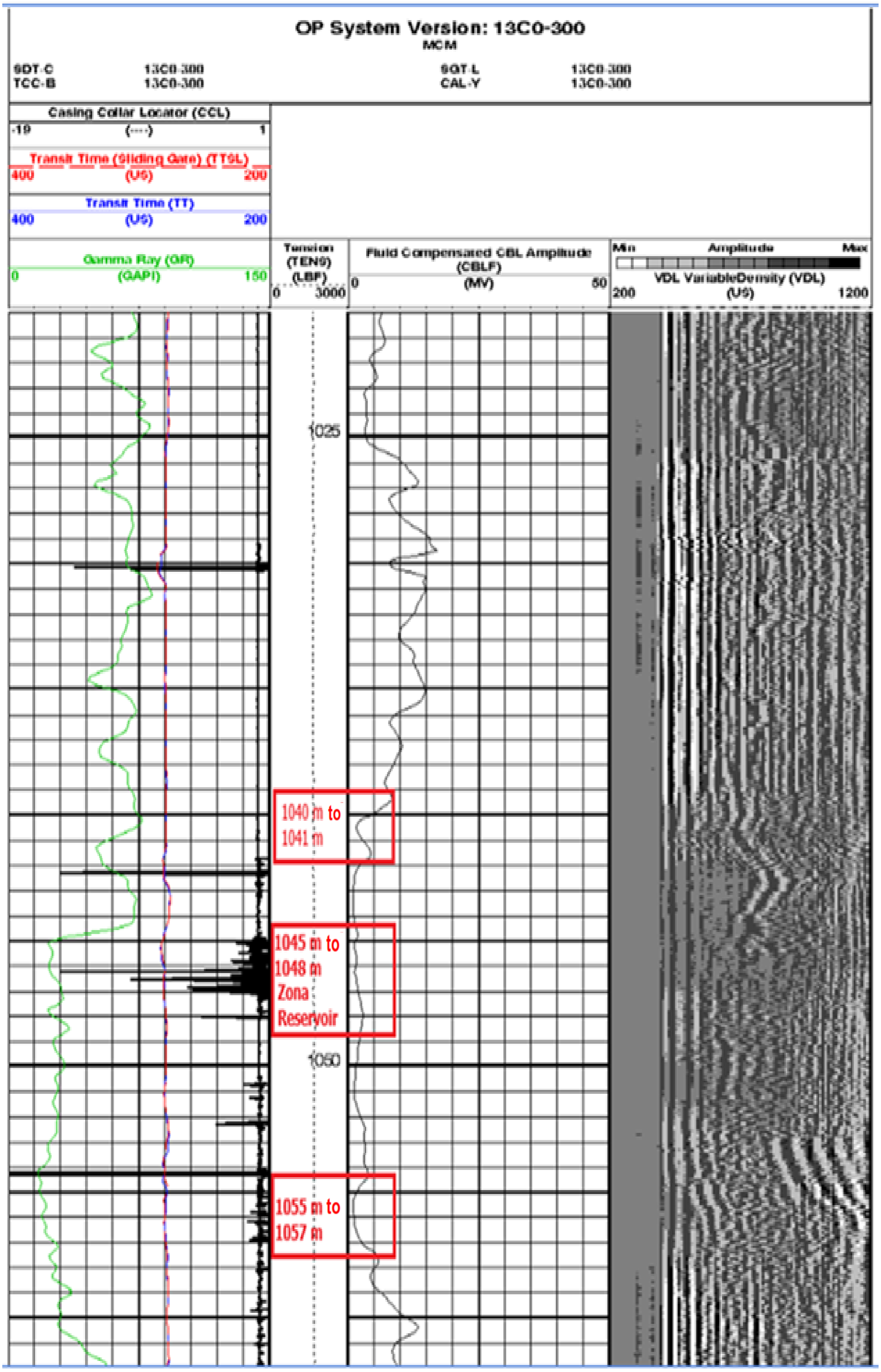

Figure 5. CBL and VDL of D-04 well after bonding repair

Final slurry design evaluation

Design of remedial cement bonding reformulation using a density of 12.5 ppg (light weight slurry) for reservoir zones which is indicated to be a CO_2 gas channelling path with the volume of cement slurry increased to cover loss and thickening time shortened to 163 minutes to accelerate the cement hardening process. The addition of spherelite material (lite cement) at 19.5% BWOC improved compressive strength.

The cementing operation was successful, as confirmed by casing pressure testing (700 psi for 10 minutes) with no leakage at a depth of 1048 mMD, and CBL/VDL values below 10 mV.

Production data analysis after bonding improvement

The efficacy of the bonding process can be determined by examining the rate of production prior to and subsequent to the implementation of the bonding process. The effectiveness of the cement bond repair was evaluated by comparing production performance before and after remediation. The decision to undertake remedial cementing was based on CBL data CO_2 gas channelling and gas migration to the surface. D-04 well was brought back into production following bonding repairs by performing perforations at the same interval, namely 1045-1048 mMD. In addition to CBL and VDL analysis, the success of the squeeze cementing can also be evaluated by analyzing production data after the bonding repairs, specifically by comparing the well's performance before and after the bonding, where there was an increase in oil production from 75 bopd to 120 bopd.

Figure 6 shows that oil production performance increased after remedial cementing. Prior to the implementation of the bonding program, the cumulative oil production of the wells was recorded at 1370 bbl, while subsequent to the implementation, it was recorded at 1452 bbl. This indicates a successful outcome. Based on the cumulative production graph, the significant increase in water cut is offset by the increase in production to oil (80% gain) and commercial gas (50% gain), hence it concluded that overall, the remedial cementing of the D-04 well successfully sealed the CO_2 gas and water zones, exhibiting a positive impact on the production performance.

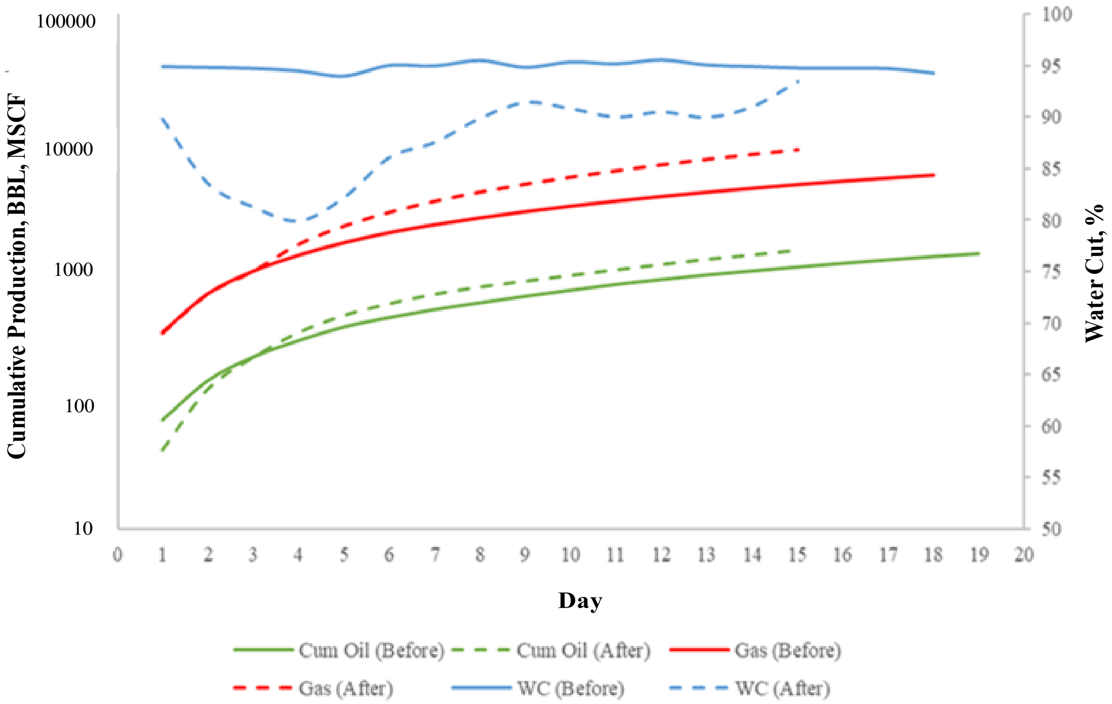

Figure 6. Production performance of D-04 well

CONCLUSION

Based on the results of data analysis and discussion, the following conclusions can be drawn: 1). Damage to the problem of ESP and its cable in the D-04 well was successfully mitigated through remedial cementing in zones affected by the gas channelling. The stabilization of WOR indicates that near-wellbore channelling was effectively controlled; 2). Cement bond improved significantly after remedial cementing. In the first stage, (1045-1048 mMD), CBL values decreased from 30 mV to 5 mV) after four formulations. In the second and third stages (1040-1041 mMD and 1055-1057 mMD), bonding decreased from 50 mV to 10 mV with a single formulation; 3). Based on the remedial cementing process carried out in the D-04 well, reformulating the cement slurry composition play critical role in optimizing cement bonding, particularly in gas and loss zone formations; 4). Based on the production performance analysis after remedial cementing, an oil production cumulative increased from 1370 bbl to 1452 bbl.

Furthermore, the authors suggest the following: 1). For future well completions, cement bonding quality in both production and isolation zones should be ensured. If poor bonding is detected, remedial cementing should be performed prior to completion; 2). For loss zones, it is recommended to use lightweight cement (around 12.5 ppg) combined with compressive strength enhancers such as spherelite or lite cement.

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DECLARATIONS

Author contribution

D. Kristanto: Supervision, conceptualization, methodology, formal analysis, data curation, investigation, writing original draft, writing review & editing. L.A. Yusgiantoro: Supervision, conceptualization, methodology, data curation, writing review & editing. N. Suhascaryo: Supervision, conceptualization, methodology, investigation, validation, formal analysis, writing review & editing. D. Rustami: Conceptualization, methodology, investigation, data curation, formal analysis, validation, visualization, Writing original draft.

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The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Competing interest

The authors declare that they have no conflict or competing interests that could have appeared to influence the work reported in this paper.

The use of AI or AI-assisted technologies

None.

GLOSSARY OF TERMS AND SYMBOLS

Terms & Symbols	Definition	Unit
CO_2	Carbon dioxide	
CBL	Cement bond log	
ESP	Electrical submergible pump	
PVT	Pressure volume temperature	
TOP	Top of cement	ft
UCI	Ultrasonic casing imagers	
UR	Upper run	
VDL	Variable density log	
WC	Water cut	%
STB	Stock tank barrel	
Bbl	Barrel	
bopd	Barrel oil per day	

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