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Comparative Cost Estimation of Plug and Abandonment Well Using SNI 13-6910-2002 and NORSOK Standard D-010 Regulations: A Case Study in the H-11 Well of Colibri Field

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ABSTRACT

This research discusses the comparative determination of appropriate method for plug and abandonment (P&A) activities in directional wells, and finding an economical cost between SNI 13-6910-2002 and NORSOK Standard D-010 regulations. Colibri field consists of several wells, including H-11 well which is a directional well, where the well was used as a reference for determination in implementation of plug and abandonment activities after the well condition has reached the economic limit. Plug and abandonment (P&A) activities in the Colibri field was implemented with designing a work plan to determine the section for the zone to be plugged by calculating the volume of cement, additives, and completion fluid, using the rig method. The result of the research is to determine the estimation costs that need to be prepared to implement well abandoned activities according to the closing year using SNI 13-6910-2002 and NORSOK Standard D-010 regulations. The cost estimation result of H-11 well using SNI 13-6910-2002 is 417,630.25 USD, while for NORSOK Standard D-010 is 813,315.77 USD. Therefore, based on the cost estimation results, the proposed method chosen for cost estimation of plug and abandoned of H-11 well in Colibri Field is SNI 13-6910-2002 regulation.

Keywords: plug and abandonment; cost estimation; cement plug; SNI; NORSOK.

I. INTRODUCTION

The extractive industry (upstream) oil and gas, is an industry that requires large capital supported by using sophisticated technology to minimize risk. One of the risks that occur is the impact on the environment. The series of oil and gas exploration and exploitation activities will directly or indirectly result in changes to the environment (Abrahamsen, E. B., & Selvik, J. T. 2020) and (Afrisca, C., & Darmawan, G. (2020). Normatively, companies, governments and all parties need to protect and process the environment to avoid pollution and/or damage to the environment and maintain the balance and sustainability of living things (Herndon, J., & Smith, D. K. 1976), and (Abrahamsen, E. B., & Selvik, J. T. 2020).

Contractors under Production Sharing Contract (PSC) have an obligation to abandon production facilities and supporting facilities by eliminating their ability to be operated again, including permanent plug and abandonment well, an activity to isolate the formation in a well that has been drilled. This aims to ensure the safety of the environment around the well and no pollution occurs due to hydrocarbons moving out of the formation or rising to the surface. After that, conduct site restoration or environmental restoration in the area of upstream oil and gas business activities. Also, provide a report on the Abandonment and Site Restoration (ASR) fund reserves for each field in a working area by including the calculation of P&A well costs included in the estimation of ASR fund nomination (SKK Migas, 2023).

Well abandoned activities or commonly known as plug and abandonment (P&A) are activities carried out when the condition of the well is considered uneconomical to produce (Abrahamsen, E. B., & Selvik, J. T. 2020). The activity carried out to stop the well is to apply pressure to the well so that the formation pressure does not burst to the surface (Herndon, J., & Smith, D. K. 1976). Based on Work Procedure Guidelines of SKK Migas No. 040/PTK/SKKIA0000/2023/S9 Rev.02 state that plug and abandonment (P&A) well is an action to permanently plug a well, among others for wells that are no longer used, no further development potential or dry holes (SKK Migas, 2023).

Permanent well abandoned can be done based on certain reasons, including problems caused by formations in certain zones, problems that occur in the wellbore such as fish, and the well has reached the economic limit so that there is no further development potential (Kaiser, M. J., & Liu, M. 2014) and (Corina, A. N. 2020). The oil and gas production of a well will decrease over time and there is a limit set by the oil and gas company called the economic limit to declare a well is no longer economical to carry out production activities (Prasetya, A. E. 2018) and (Corina, A. N. 2020). According to Kaiser, M. J. & Dodson, R. (2007) and Kaiser, M. J., & Liu, M. (2014), the status of a well are temporarily drilled, completed drilling, while in production/injection, temporarily out of production, temporarily closed, and permanently closed. At the agreed contract period, the end of production will see the well permanently shut in. This is done when:

1. Hydrocarbons are found in marginal quantities, making the well uneconomical to produce. Abandoned will take place immediately after drilling.
2. The production of the well for a certain period of time and the production of the well decreases until it does not touch the economic limit.
3. The well produces for a certain period of time and there is an irreparable well leakage problem that endangers safety.
4. The completion of the contract period for the oil and gas working area and the field will not be put back into production.

Given the potential signatures, permanent well abandoned should be implemented in accordance with applicable regulations, as the ultimate goal is environmental protection and management (Lukmana, A. H. 2019). The National Standardization Agency (2002) states that "all wells should be abandoned in such a way as to ensure belowground isolation of hydrocarbons and to maintain fluid movement from the formation into the wellbore." Well abandoned design in Indonesia has been regulated in SNI-13-910-2002 which has been established by the National Standardization Agency (2002). Based on SNI 13-6910-2002, the Operation Stages of permanent well abandoned are divided into reservoir abandonment and surface plug.

According to Kaiser, M. J. (2017), the stages of permanent well abandoned are as follows: Planning, Obtaining necessary permits and approvals, Permanent well abandoned operations, Wellhead removal, and Final reporting. Well abandoned activities or commonly known as Plug and Abandonment (P&A) are activities carried out when the condition of the well is considered uneconomical to produce. The activity carried out to stop the well is to apply pressure to the well so that the formation pressure does not burst to the surface. Technology Subgroup (2011), states that well abandoned is necessary to create barriers that prevent hydrocarbon leakage from the formation into the wellbore or to the mudline or surface and prevent pollution of water sources around the well environment. There are several displacement methods commonly used for plug cementing activities, namely: Balanced Plug, Dump Bailer, and Two Plug Method.

In this study, the estimation of abandonment and site restoration (ASR) fund planning for H-11 well in the Colibri field will be carried out when H-11 well has reached the economic limit in the future. The calculation of the estimated year when the well reach the economic limit is proven by calculating the decline curve analysis method with a 30-year and 50-year forecast. Well H-11 is a production well located in the Colibri Field, Northern part of the West Java working area. The structure of Well H-11 is in the Ciputat sub-basin of the North West Java basin. Northern West Java consists of two main basins, are the Northwest Java Basin (NJB) and the Asri Basin (AB). The Colibri field is located at the Western end of the Ciputat sub-basin with sandstone and limestone as constituent rocks. The stratigraphy in the Colibri field range from old to youngest are the Jatibarang, Cibulakan, Parigi and Cisubuh formations. The H-11 well is a production well that was estimated by the calculation of the exponential decline curve analysis (DCA) method to reach the economic limit; therefore, a well abandoned planning activity is carried out in 2066.

II. THEORY AND METHODOLOGY

2.1. Theory

The regulations usage in the plug and abandoned of H-11 well in the Colibri field refers to the Minister of Energy and Mineral Resources Regulation No.15/2018 Article 10 which states that the implementation of Post-Operation Activities, the Contractor is required to use Indonesian National Standards and/or applicable International Standards in accordance with the approved Post-Operation Activity plan (Minister of Energy and Mineral Resources Regulation, 2018).

2.1.1. SNI 13-6910-2002 (Badan Standardisasi Nasional, 2002)

a. Isolation zone in open holes

Isolation zone in open holes, cement plugs should be placed at least 100 ft below the layer up to 100 ft above the layer containing oil, gas or water to isolate the fluids in the layer where they are encountered and prevent flow to other layers or to the surface. Placement of additional cement plugs is required to prevent potential fluids from migrating into the wellbore. Cement plugs should be installed in the deepest casing by the plunger method at least 100 ft below the casing shoe to 100 ft above the casing shoe, if there is an open hole below the casing. Alternative methods of cement plugs along the casing shoe are as follows:

1. Installation of cement retainer and cement plug. Cement retainers should be capable of effective back pressure control and be placed at least 50 ft and no more than 100 ft above the casing shoe. Meanwhile, the plug cement should be installed at least 100 ft below the casing shoe and no more than 50 ft above the retainer.

2. Permanent type bridge plug installed at 150 ft above the casing shoe with a minimum cement plug 50 ft above the bridge plug. This is used when lost conditions occur or are expected to occur. circulation in the formation. Bridge plugs must be tested in accordance with applicable regulations.

b. Plugging or isolating perforation intervals

Cement plug installation shall be carried out by pushing through all uncemented perforations. The cement plug press shall extend at least 100 ft above the perforation interval to 100 ft below the perforation interval or to the nearest casing plug. Methods that can be used for replacement preference and placement of cement plugs, such as:

1. Installation of cement retainer and cement plug are both mandatory. Cement retainers shall be capable of effective back pressure control and shall be installed at least 50 ft and a maximum of 100 ft above the perforation interval. While cement plugs must be able to reach a minimum of 100 ft below the perforation interval and 50 ft above the retainer.
2. The permanent-type bridge plug shall be installed at 150 ft above the crest and the perforation interval at least 50 ft above the bridge plug.
3. Installation of cement plugs at least 200 ft long using the plunger method with the base of the plug at a distance of 100 ft above the top of the perforation interval.

c. Casing stump plugging

The methods used when the casing is cut and removed, the casing stump must be plugged with:

1. Stumps within the casing string must be plugged with cement plugs a minimum of 100 ft above and 100 ft below the stump. Alternatives that can be used to replace the cement plug that covers the stump, as follows: cement retainer or permanent type bridge plug should be installed at least 50 ft above the stump with at least 50 ft of cement; and cement plugs that are at least 200 ft long shall be installed with the base of the plug at least 100 ft above the stump.
2. Zone plugging or open hole isolation shall be implemented as applicable, if the stump is located under a larger casing.

d. Annulus space blockage

The annulus space that can be connected to the open hole leading to the mud line must have a layer of cement with a minimum depth of 200 ft.

e. Surface plugs

The length required to place the cement plug is at least 150 ft and is 150 ft below the mud line. Mud lines that reach the smallest casing size must be filled with plugs.

f. Plug testing

The methods used for the placement and position of the first plug below the surface plug, namely:

1. The operator has an obligation to perform a load test with a minimum weight of 15,000 pounds on the cement retainer plug, or bridge plug. If the cement is above the separation plug or retainer, no test is required.
2. The operator has an obligation to carry out a compressive test of the cement plug with a minimum pressure of 1000 psi for 15 minutes per section, The result shall not be less than 10% of the test pressure.

g. Fluid left in the hole

Each consistent interval of the hole between the various cement plugs should be filled with fluid of sufficient specific gravity or appropriate to the zone conditions to have sufficient hydrostatic pressure to exceed the maximum formation pressure in the interval between plugs at the time of abandonment.

h. Site clearance

All wellheads, casing, piles and other disturbances shall be removed to a depth of at least 30ft below the resistant surface for onshore operations and 150ft below the mud line for offshore operations. The Contractor shall ensure that the site is free of any interference. Where subsea wellheads or other obstructions do not pose a nuisance to other persons using the seabed or authorized users of the area, the need to remove them to protect the site may be limited or eliminated. Government environmental regulations must be realized to restore the area to its original condition.

2.1.2. NORSOK Standard D-010

Wells that have been permanently capped are recommended to be kept under review to consider evaluating the potential impact of well barriers on the chemical and geological processes that are expected to occur. "barriers" serve to prevent leakage and mitigate potential hazards that can occur during well drilling, production and workover activities (NORSOK Standard, 2004).

Based on NORSOK Standard D-010, well barriers are classified into two different categories, as follows:

1. Primary Well Barrier; This is a barrier that is located adjacent to hydrocarbons. Assuming the primary well barrier is functioning effectively, it has the capacity to limit hydrocarbons that are pressurization. If the primary well barrier is not functioning, this is due to a leak or a valve that fails to close.

2. Secondary Well Barrier; A barrier that serves to block the flow of pressurized hydrocarbons out of the well. If there is a failure of the secondary well barriers, there is the potential for the tertiary barrier to effectively block the flow of hydrocarbons.

A general description of the two categories of well barriers can be understood as, in the process of stopping the flow of oil wells, hydrostatic pressure serves as the primary barrier, while surface equipment such as Blow Out Preventer (BOP) and casing cement serve as secondary barriers. Having at least one effective well barrier between the surface and the potential flow source is essential, except for subsurface formations with hydrocarbons and/or potential flow that require two well barriers. When performing plugging activities in reservoirs, it is important to consider the potential that can occur in connection with this part of the well (if the formation collapses, etc.) and to be able to create certain well barrier elements. Every complete borehole must be isolated. Whether or not there is pressure or flow potential, the last open hole section of a borehole cannot be permanently abandoned without installing a permanent well barrier.

The permanent well barrier will extend across the entire well section, including all annuli and act as a barrier, both vertically and horizontally. Because of this, well barrier elements placed in the casing and as part of the permanent well barrier, should be placed at depth intervals where there are well barrier elements of validated quality in all annulus. The properties that a permanent well barrier needs to have are Impermeable, Long-term integrity, Non shrinking, Ductile - (Not Brittle) - able to withstand mechanical / impact loads, Resistance to various chemicals/substances (H_2S, CO_2 and hydrocarbons), and Discussion, to ensure bonding with cost.

2.2. Methodology

The methodology used in this research is qualitative and quantitative. The qualitative method is used to plan the implementation of well abandoned activities at H-11 well. While the quantitative method is used to calculate the need for cement slurry, additive, completion fluid and rig used along with the costs required in well closure activities. Details of the flowchart methodology is shows in Figure 1.

Figure 1. Research methodology in the Colibri field

2.2.1. Qualitative Analysis using DCA Trial Error and x^2 Chisquare-test Methods

Decline Curve Analysis (DCA) is one of the methods that can be used to calculate the reserve estimate of a well, calculations with this method are more commonly used because it only requires historical production data. The decline in production value observed in the production history data is a depiction of the reservoir productivity of a well without the problem of decreased production caused by several external factors, which reservoir conditions must be stable to be able to extrapolate the decline in the form of a curve (Arps, J. J. 1944) and (Rukmana, D., et al. 2018). According to Arps, J. J. (1944) and Rukmana, D., et al. (2018), decline curve analysis (DCA) is divided into three types, namely exponential, hyperbolic, and harmonic. The value to determine the type of decline used is commonly known as "b". The value of b only ranges from 0 to 1. If the value of b=0 then the curve type is exponential. If the value of $0 \leq b \leq 1$ then the type of curve is a hyperbolic curve. Meanwhile, if the value of b = 1 then the type of curve is harmonic. The type of decline curve will be determined before the calculation of the estimated reserves of a reservoir. The determination of the type of decline curve used in the research is the trial error and x^2 Chisquare-test method because it has more concrete results.

2.2.2. Quantitative Analysis of Cementing Calculation

Good cementing results not only depend on techniques and equipment that can work properly, but wise calculation and planning of cementing is required. The calculations are as follows:

1. Determine Top of Cement and Bottom of Cement targets.
2. Taking into account the capacity of a space to be cemented and the volume of cement slurry in the casing, it can be calculated by:
   - Calculating the Casing Capacity

     $$\text{Casing Capacity (bbl/ft)} = \frac{ID^2}{1029.4} \quad (1)$$

     where:
     ID = Inside diameter of casing (inch)
   - Calculating the Length of the Perforation Column
     = bottom of perforation – top of perforation (2)
   - Taking into account the additional safety factor value according to the provisions used
     = Length of the perforation column + (top of perforation – top of cement) + (bottom of cement – bottom of perforation) (3)
   - Calculating the volume of slurry
     = Length of cement column, ft x Casing Capacity (4)
3. Calculate the volume of cement slurry that fills the perforation
   - Calculating Number of Perforation Holes
     = Length of the perforation column, ft x density of perforation, spf (5)
   - Calculating the volume of cement filling the perforation holes

     $$= \frac{\text{total perforation holes}^{\text{hole/ft}} \text{ x } cement\ slurry^{\text{cuft/hole}}}{5.615} \quad (6)$$

     where:
     Based on the Injectivity Test, Cement Slurry is divided into three parts, are:
     Tight Formation = 0.1 cuft/hole
     Moderate = 0.2 cuft/hole
     Loss/Sucking (>1 BPM) = 0.4 cuft/hole
4. Taking the Cement Top into account when stringing in the hole
   - Calculating the height of cement when stringing in the hole, ft

     $$= \frac{\text{Volume cement, bbl}}{sann\ casing^{\text{bbl/ft}} \text{ x } sann\ \text{DP}^{\text{bbl/ft}}} \quad (7)$$
   - Calculation top of cement when string in hole, ft
     = bottom of cement – height cement when string in hole (8)
5. Calculating the total cement slurry required
   = Volume of cement slurry in casing column + volume of cement slurry filling perforation holes + dead volume + %Excess, bbl (9)
6. Calculating the number of cement sacks required

   $$\text{Sack of Cement, sack} = \frac{\text{Total volume cement slurry, bbl x 42}}{\text{yield cement}} \quad (10)$$
7. Take into account the volume of additives used

Va = Wc x Vu (11)
where:
Va = Volume of additives to make slurry, gal
Wc = Quantity of dry cement used, sak
Vu = Volume of additive per bag of cement, gal/sak

8. Calculating completion fluid volume
= Casing capacity (bbl/ft) x Length of column (ft) (12)

9. Calculating Horse Power

$$\text{Rig Capacity, HP} = \frac{W \times Vh}{33.000} \times \frac{1}{n} \quad (13)$$

where:
W = Weight of drill pipe
Vh = Upward speed of traveling block, ft/min
ὴ= Efficiency hook to draw work

10. Calculating P&A Cost
    a. Cost of sack cement used, USD
    b. Rig rental cost, USD
        - Calculation of ASR Cost Estimation through Time of Money Concept Approach
            1. Determine the Volume and Components of the ASR Activity Plan
            2. Establish an Estimated Market Value for each Cost Contributing Component
            3. Calculate the Volume of Activity Plan Components multiplied by the unit cost of each ASR Cost Component.
            4. Obtained current ASR Cost Value
            5. Using the concept of time value of money, the cost at year N will be obtained by calculating the future value (year N).

$$FVn = PV \times (1 + r)n \quad (14)$$

where:
FVn = ASR cost in year n
PV = ASR cost at the time of calculation
r = Average inflation rate
n = Remaining ASR fund collection period

Furthermore,

$$\frac{FV_n - \text{asr fund balance}}{n} = \text{Total ASR Fund Reserve in the Year of Calculation} \quad (15)$$

III. RESULTS AND DISCUSSION

3.1. Data Preparation

The research data was obtained from H-11 well in the Colibri Field located in Northern West Java. The data available are well schematics, production data history, tubing and casing details, well perforation depth, and cement information. These data will be used for planning of cement, additive, and completion fluid volumes, work program, operating time, and economics for cement plug and abandonment work. In the plug and abandonment work of H-11 well, the work program for well abandoned planning activities refers to SNI 13-6910-2002 and NORSOK D-010 regulations.

3.2. Plug and Abandonment (P&A) Planning

The H-11 well was directionally drilled to a final depth of 8733.59 ftMD or 7917.58 ftTVD. The casing installation stage began with hammering the 30" casing conductor to a depth of 0-118.1 ft. Next, a hole was drilled using a 26" bit, and a 20" surface casing was installed with a depth of 0 - 2424.5 ft. After that, continued drilling using a 17 ½" bit, and installed 13 3/8" intermediate casing with a depth of 0 - 3595.8 ft. Then, continued drilling with a 12 ¼" bit and installed 9 5/8" production casing to a depth of 0 - 7124.3 ft. After that, drilling with an 8 ½" bit, and installing a 7" liner at a depth of 6886.02 - 8730.3 ft.

3.2.1. SNI 13-6910-2002

The use of data in planning plug and abandonment activities is obtained from the H-11 well report. The plug and abandonment work plan on the H-11 well in Figure 2 by referring to the SNI-13-6910-2002 regulation which is described as follows.

1. Close the perforation interval zone with cement plug at a depth of 8298.95 - 8638.45 ft. For this planning stage, the author has adjusted to the SNI-13-6910-2002 regulation which explains that cement plugs must be installed by the pushing method through the entire perforation interval and cement plugs must cover the entire perforation interval with a minimum distance of 100 ft above the perforation interval to a minimum distance of 100 ft below the perforation interval or to the nearest casing plug. If there are two adjacent perforation intervals, only one cement plug shall be used.
2. Seal the perforation interval zone and casing stump with cement plug at a depth of 6396.06 - 6986.02 ft. For this planning stage, the author has made adjustments to the SNI-13-6910-2002 regulation which explains that when the casing is cut and pulled out, the casing stump must be plugged with a cement plug that is able to cover a minimum distance of 100 ft above the stump and 100 ft below the casing stump, and for the regulation of the perforation interval zone, it is back to the first point.
3. Cover the surface with cement plug at a depth of 0 - 150 ft. For this planning stage the author has made adjustments to the SNI-13-6910-2002 regulation which explains that a cement plug of at least 150 ft in length shall be placed with the top of the cement plug at 150 ft below the mudline. Cement plug shall be placed in the smallest casing that reaches the surface.

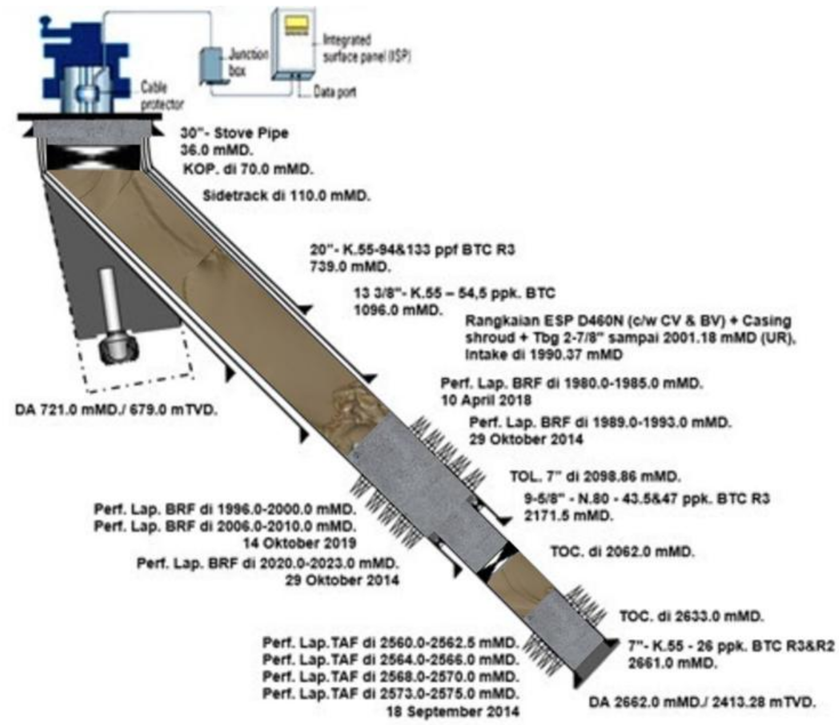

Figure 2. Well schematic of H-11 well after P&A using SNI 13-6910-2002 method

3.2.2. NORSOK Standard D-010

The use of data in planning plug and abandonment activities is obtained from the H-11 well report. The plug and abandonment work plan on well H-11 in Figure 3 by referring to the NORSOK Standard D-010 regulation which is described as follows:

1. Close the perforation interval zone or primary well barrier with a cement plug at a depth of 8300.52 - 8638.45 ft. For this planning stage, the author has made adjustments to the NORSOK Standard D-010 regulation which explains that the placement of the primary well barrier cement plug serves to isolate the layer that drains fluid to the formation and to the surface, with formations that have normal or excess pressure, impermeable to water from the surface / seabed.
2. Placing the secondary well barrier after the primary well barrier with cement plug at a depth of 8202.09 - 8300.52 ft. For this planning stage, the author has made adjustments to the NORSOK Standard D-010 regulation which explains that the secondary well barrier functions as a barrier to potential incoming flow and is placed after the primary well barrier to block fluid flow.
3. Close the perforation interval zone or primary well barrier and top of liner with cement plug at a depth of 6397.64 - 7222.77 ft. For this planning stage, the author has adjusted to the NORSOK Standard D-010 regulation as the placement of the primary well barrier cement plug serves to isolate the layer that drains fluid to the formation and to

the surface. And secondary well barrier that serves as a well barrier because the top of the liner is generally not cemented as in the casing part for the annulus, therefore in the plug and abandonment top of liner activities required placing cement plug. The cement plug is placed on the next casing shoe so that it can reach the top of the liner.

4. Placing the secondary well barrier after the primary well barrier with cement plug at a depth of 6299.21 - 6397.64 ft. For this planning stage, the author has made adjustments to the NORSOK Standard D-010 regulation which explains that the secondary well barrier functions as a barrier to potential incoming flow and is placed after the primary well barrier to block fluid flow.
5. Close each section of casing shoe with cement plug at a depth of 3497.37 - 3694.22 ft. For this planning stage, the author has adjusted to the NORSOK Standard D-010 regulation which explains that the cement plug placed in each casing shoe functions as a secondary well barrier which aims to help back-up to the main barrier or primary well.
6. Close each section of casing shoe with cement plug at a depth of 2326.11 - 2522.96 ft. For this planning stage, the author has adjusted to the NORSOK Standard D-010 regulation which explains that the cement plug placed in each casing shoe functions as a secondary well barrier which aims to help back-up to the main barrier or primary well.
7. Close the top zone near the surface with cement plug at a depth of 0 - 150 ft. For this planning stage, the author has adjusted to the NORSOK Standard D-010 regulation which explains that to minimize the risk of contamination with intervals containing fresh water, it is necessary to place a cement plug to isolate the fresh water interval. Generally, this interval exists in shallow wells, so it is necessary to cement plug the surface zone.

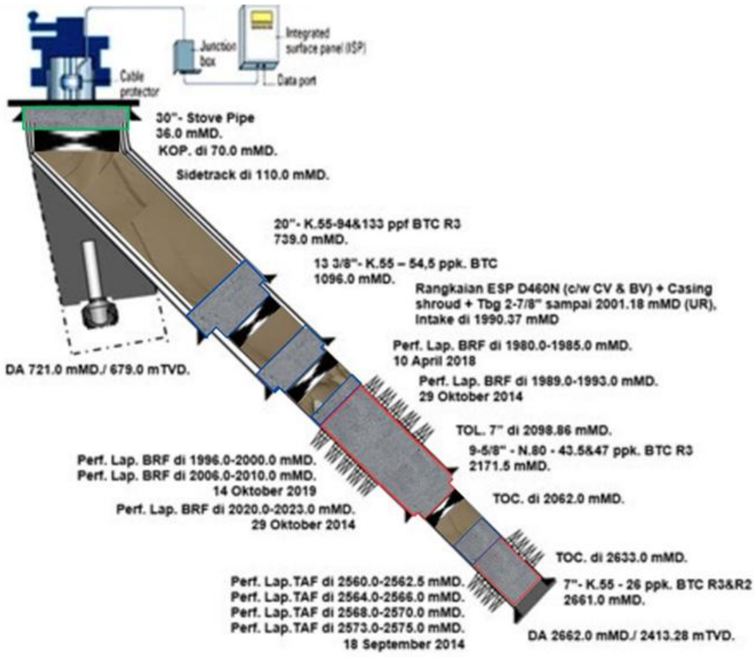

Figure 3. Well schematic of H-11 well after P&A using NORSOK Standard D-010 method

Best Practices: A literature review of field case studies on plug and abandonment works is the source of the best practices discussed in this paper. In this paper, regulatory options that should be considered during well abandonment planning and good plug and abandonment planning are described. The operator must ultimately decide how the well will be permanently abandoned and whether this method will be beneficial from a safety and environmental protection standpoint.

Cement Design: Cement plugs should be designed for static bottom hole conditions at each depth plug setting. The expected bottom hole pressure and temperature are the controlling factors in slurry selection. The slurry density should be designed for the bottom hole pressure. The additive concentration should be based on the bottom hole temperature to ensure timely placement and development of compressive strength. In the design of cement plugs for well H-11, grade G cement is used with additives such as silica flour, dispersant liquid, retarder liquid, fluid loss control liquid, bonding agent, and deformer liquid. Each section of cement plug uses a different volume of additives.

Cement Placement: Cement should be placed in a clean and known environment. The balanced plug method was used to place cement plugs in H-11 well. Although this method may be an efficient and inexpensive way to isolate perforations, it still has some risks. This method involves lowering a drill pipe down the wellbore to the location where a cement plug will be made. To prevent mud contamination, pre-flushing is pumped before the cement and followed by a spacer or barrier fluid.

3.3. Calculation of Plug and Abandonment (P&A)

The following is a calculation the cement plug volume for the perforation zone of H-11 well. Based on the calculated length of the cement column from the bottom of the lower perforation to the upper perforation is 16.40 ftMD. Adding a safety margin of 100 ftMD above the top perforation and 100 ftMD from the bottom perforation in accordance with regulations and standards, the result is 644.62 ftMD. The calculated volume of cement slurry required to fill the casing column is 24.67 bbl. From the calculation, the total perforation is 82.02 holes/ft with the volume of cement slurry entering the perforation P&A design with SNI 6910-2002 holes is 1.46 bbl. The cement height when the string (tubing) is in the wellbore is 773.49 ftMD with the top of cement (TOC) when the string is in the wellbore is 7441.73 ftMD. The total cement slurry required for the perforation zone including cement slurry for casing volume, cement slurry volume in the perforation zone, and cement slurry volume with dead volume and excess was 36.96 bbl. Total cement sacks required slurry yield equal with 1.57 cuft/sack is 133 sacks. The calculation results of cement volume referring to SNI-6910-2002 and NORSOK D-010 standard for H-11 well, and the total volume of cement slurry for P&A obtained for each regulation are shows in Table 1 dan Table 2, respectively.

Table 1. Cement slurry P&A of H-11 well using SNI 13-6910-2002

Cement plug	Length of cement (ft MD)	Cement volume (bbl)	Cement quantity (sack)
1	339.50	25.58	92
2	589.96	69.79	250
3	150	13.98	50
Total		**109.35**	**392**

Table 2. Cement slurry P&A of H-11 well using NORSOK standard D-010

Cement plug	Length of cement (ft MD)	Cement volume (bbl)	Cement quantity (sack)
1	337.93	25.51	92
2	98.43	6.77	25
3	825.13	82.59	296
4	98.43	10.21	37
5	196.85	10.53	38
6	196.85	10.53	38
7	150.00	13.98	50
Total		**160.11**	**576**

A comparative analysis of the SNI-6910-2002 and NORSOK D-010 was performed in order to determine the benefits and drawbacks of each regulation for plug and abandonment well work. Analysis will then be used to select the appropriate regulation by taking into account the condition of the well and the economics of P&A activities.

3.4. Section of Cement Plug

Cement plugs are positioned in the perforation interval isolation zone, top isolation of the liner, and surface insulation in accordance with SNI 13-6910-2002 as shown in Figure 2. The existence of an over pressured zone is not taken into consideration when placing the cement plug, therefore if an issue arises during the P&A work, mitigation is required. It is not necessary to insert a cement plug for every component of the casing shoe section, provided that the cement plug's pressure can sustain the well's formation pressure. Since there are no additional hydrocarbon zones surrounding the well and the hydrocarbon zone is thought to be the only one, the isolation of the hydrocarbon-bearing zone is disregarded.

Cement plugs are positioned in the following areas: interval isolation zone, top of liner isolation, hydrocarbon bearing isolation zone as a secondary well barrier, isolation for each section of casing shoe, and isolation of the surface water zone (fresh water), with reference to NORSOK D-010 in Figure 3. It is necessary to place a cement plug across the transition interval, where the plug's length is at least 200 feet or at least reaches normal pressure in certain casing sections, in order to account for the existence of an over pressured zone or abnormal pressure. Cementing must be done in each segment of the casing shoe while taking into consideration variations in the rock lithology and the unique formation of each piece. Considering a zone that contains other hydrocarbon intervals around the well so that a cement plug is needed in that zone.

3.5. Work Program

The length of time required to carry out the H-11 well with SNI 13-6910-2002 regulation takes 7.9 days operation, meanwhile with NORSOK Standard D-010 regulation is about 12 days of operation.

3.6. Economic Analysis

Estimated costs required based on calculations in 2024 with SNI 13-6910-2002 regulation, H-11 well requires 148,043.59 USD. Whereas with the NORSOK D-010 regulation, H-11 well costs 288,308.10 USD. And for estimated costs required based on calculations 2066 for H-11 well with SNI 13-6910-2002 regulation costs 417,630.25 USD, meanwhile, calculations with NORSOK D-010 regulation cost 813,315.77 USD. The factors affecting the total estimated cost of P&A activities are the use of both SNI 13-6910-2002 and NORSOK D-010 regulations, the difference in well depth, the number of plug sections, the length of the cement area, the volume of cement required, the volume of additives used, and the volume of completion fluid added, as well as the cost of rig rental.

IV. CONCLUSION

Based on the results of the analysis and research that has been carried out, it can be concluded that H-11 well was planned to be closed in 2066, due to have reached the economic limit. The cementing method used in this plug and abandonment activity is the balanced plug method, and the operation uses conventional method or with a rig that has a power rating capacity of 550 HP for a depth of 8307.09 ft MD and 8733.59 ft MD or 7917.59 ft TVD with a drill pipe size of 3 ½ inch. Plug and abandonment activities with SNI 13-6910-2002 regulation for H-11 well required a working time of 7.9 days, while the NORSOK Standard D-010 regulation requires 12 days. Based on the results of the economic calculation analysis, a comparison of the estimated costs in each year of SNI 13-6910-2002 regulation for Well H-11 costs is 417,630.25 USD, while the NORSOK Standard D-010 regulation requires a cost of 813,315.77 USD. Based on the results of a comprehensive analysis that has been carried out technically and economically for H-11 well of Colibri field, the use of SNI 13-6910-2002 regulation is more efficient and economist to be implemented due to the shorter operating time and has not require a lot of materials.

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GLOSSARY OF TERMS

ASR	Abandonment and Site Restoration
NW	North West
DCA	Decline Curve Analysis
CTU	Coiled Tubing Unit
BPM	Barrel per Minute
MD	Measured Depth
TVD	True Vertical Depth
KOP	Kick of Point
CF	Completion Fluid
HP	Horse Power
SF	Safety Factor
Sann	Annulus Capacity, bbl/ft
ὴ	Efficiency
W	Weight, lbs
Vh	Power Rating, ft/min

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