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Indonesia Well Abandonment Standard Gap Analysis; A Review and Suggestion

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Abstract

The old oil and gas wells of approximately 70% are found to have no economic value in Indonesia, leading to being abandoned during the end of their lifecycle, as ruled by the government. This is part of decommissioning an entire field with an environmental preservation program, known as an Abandonment and Site Restoration (ASR). The program involves the evaluation of international permanent abandonment standards, as references for the designs, comparisons, and assessments of Indonesia's policies. It also provides contrast gap analysis and suggestions in ensuring a proper permanent plug and abandonment approach, to avoid any future leaks or re-abandonment operations. Therefore, this study aims to determine and evaluate the gap analysis between Indonesia and International Well Abandonment Standards, as well as OGUK and NORSOK D-010. The results showed that abandonment activities had improvement opportunities philosophy, and practice, used for plugging/isolations, control lines, as well as reservoir and annular barriers. In addition, literature studies were performed to understand the abandonment philosophy for all reviewed standards, to provide proper suggestions or improvements.

INTRODUCTION

The Indonesian Ministry of Energy and Mineral Resources (ESDM) stated that there were approximately 13,824 old wells scattered across the country (onshore and offshore), soon to be abandoned (Hanum, 2020). This excludes the wells presently managed by an operating company under production sharing contracts. Approximately 70% of these oil and gas wells are entering the end of their life cycle, as several matured fields no longer have economic values. Therefore, this leads to a permanent abandonment, according to the regulations meeting safety principles, company standards, and state policies (Afrisca & Darmawan, 2020). This is often known as abandonment waves.

Abandonment is found to impact the investment of operating companies, as outlined in the Ministerial Regulations of Energy and Mineral Resources (ESDM) No. 15, 2008. This indicates that efficient abandonment operation should be evaluated, to ensure proper planning and execution. It is also part of decommissioning an entire field with environmental preservation, often known as Abandonment and Site Restoration (ASR) (Afrisca & Darmawan, 2020). In clause 10 of the document, the operating companies were shown to also use international abandonment standards.

The well designs in Indonesia vary from 2-7 casing string constructions, with reservoir depths ranging between 200-4,000 m. Several explorations and productions also have an interest in producing shallow and deep oils, as well as profound high-pressure reservoirs containing sour gas. However, the presence of onshore hydrogen sulfide (H_2S) and carbon dioxide (CO_2) leads to dangerous and difficult operations on the field, increasing the need to prevent the release of sour gases (Haris et al., 2012). This indicates that all well designs should be in line with the purpose of the reservoir fluids/pressure/temperature.

Abandonment is the final activity performed on well designs, including the establishment of permanent barriers in the wellbore, to retain integrity with no intention of future re-entry (*ISO - ISO 16530-1:2017*

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- *Petroleum and natural gas industries — Well integrity — Part 1: Life cycle governance*, 2017). Besides being performed at the end of their life cycle, abandonment should also be conducted when the wells have severe integrity issues and no economic or productive values.

Mainguy et al. (2008) estimated the effect of permanent cement plugs based on the external pressure, thermal, and stress changes produced from a global equilibrium restoration, within a hydrocarbon reservoir. The results showed that the main risk was a tensile failure, because of the low strength of the cement. It also justified future cement failures or leaks on abandonment wells. Cement sheath failure is one of the reasons several wells experience integrity problems, as stated by Khalifeh & Saasen (2020). Furthermore, the study of Kaiser (2017), showed that several wells required remediation after initial abandonment was completed with remediating probability of 1.8% for shallow water depth designs (400 ft.). The cost of unwanted remedial jobs is likely a major and difficult task in conducting offshore or onshore leakage on abandoned wells. Vignes (2011) stated that there were approximately 2200 abandoned wells in Norway, with no specific data on the exact leakage sources. In addition, the study of Kang et al (2014, 2016) concluded that methane emissions from old abandoned oil and gas wells were a significant source to the atmosphere. This indicated a lesson for Indonesia, as several wells were not properly abandoned after the departure of the Dutch.

Kaiser (2017) stated that several countries such as the United Kingdom and Norway had adopted performance-based approaches, which specified achievable objectives for operators through technological flexibility. Meanwhile, permanent abandonment procedures and standards are mostly a prescriptive approach in US waters, setting clear rules for the industry to abide (Kaiser, 2017). This is quite similar to the policies of Indonesia, where procedures are inflexible and strict. The study of Moeinikia et al. (2018) reported that permanently abandoned wells should be plugged with an eternal perspective, by considering the effect of several geological and chemical processes according to NORSOK D-010 Rev.4.,2013. For hydrocarbon-bearing and abnormally pressured zones, flow potentials to the surface should be isolated with two barriers. In addition, the common philosophy is to have eternal abandonment with permanent barriers.

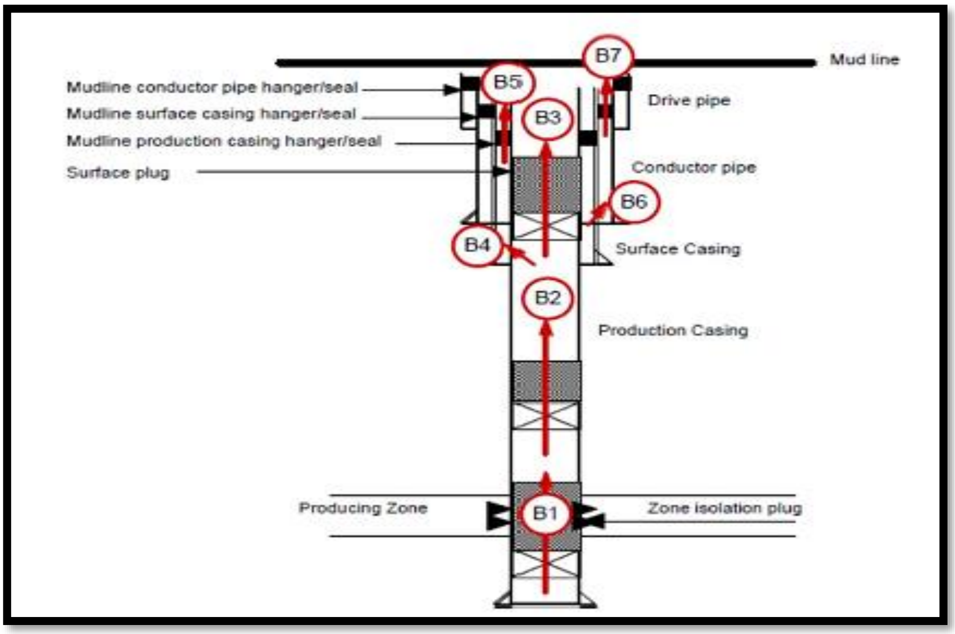

Figure 1. Permanent abandonment with similar reference to SNI13-6910-2002 and possible leak paths. B1, B2, B3 are potential leak paths from the squeezed perforation zone to the surface. Others are the potentials from the production to the outer containments, as well as a breach to surface (Kaiser, 2017)

This study aims to determine the gap analysis between Indonesia and International Well Abandonment Standards (*ISO - ISO 16530-1:2017 - Petroleum and natural gas industries — Well integrity — Part 1: Life cycle governance*, 2017) as well as Oil & Gas UK (2015) and Norsok (2013). It also aims to evaluate the existing Indonesia permanent well abandonment with international policies, while further suggesting several improvements plans for abandonment waves.

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METHODS

This is a literature study based on assessing and reviewing related standards, journals, publications, articles, and books concerning permanent well abandonment designs, operations, and improvements. The results obtained were compiled, analyzed, and presented as a gap analysis on the present rank of Indonesia abandonment standard. They also provided improvement suggestions needed in the present policies of the country.

Indonesia's Standard on Well Abandonment

This study reviewed SNI (*Standar Nasional Indonesia* – Indonesia National Standard) 13-6910-2002, concerning *Drilling Operations for safe onshore and offshore performances in Indonesia*, Section 6.10, "*Abandonment of Wells*", page 84-89.

Based on this literature, the P&A requirements of Indonesia was quite similar to the Outer Continental Shelf Lands Act (OCSLA) of the US, and the *Code of Federal Regulations* (CFR) laid out in the OGIP Report 585, 2017, and 30 CFR 250, Subpart Q. Section 250.1712. Figure 2 shows an illustration of plug and abandonment acceptable options for a perforated cased hole, as outlined in the Indonesian standard.

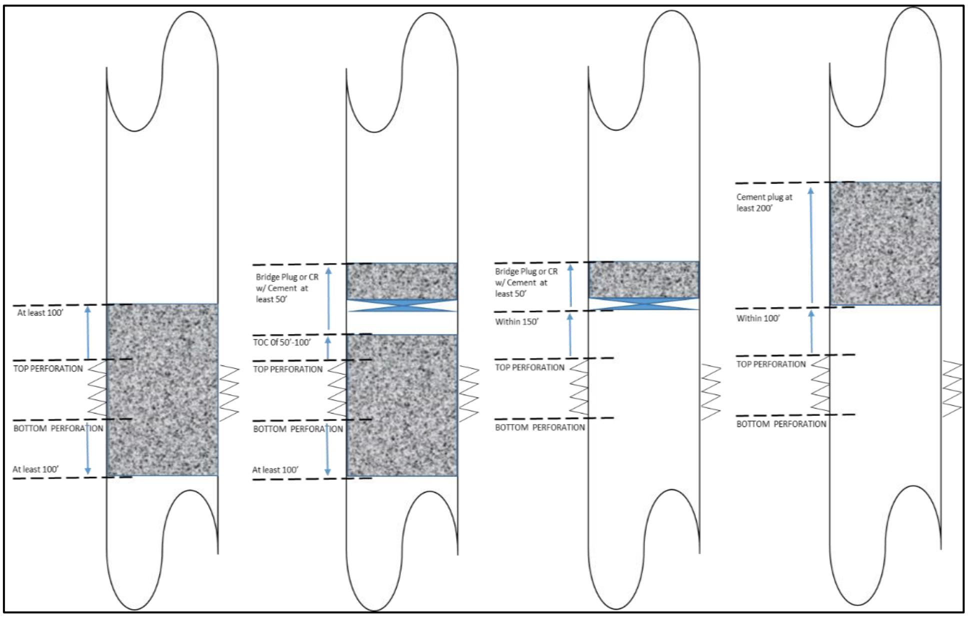

Figure 2. Plug and Abandonment acceptable options refer to SNI13-6910-2002 for an open hole, perforation, near-surface, and annulus casing isolations. From the figure, there are some options, although attempts should be made before selecting an un-squeezed perforated zone (Source: Prasetya et al., 2018)

International Standards of Well Abandonment

ISO 16530-1

The abandonment phase is known to determine the requirements in permanently abandoning a well, which is the final activity performed on the hole design, including the establishment of eternal barriers. Based on this description, the study reviewed ISO-16530-1, 2017, concerning Petroleum and natural gas industries–Well integrity, Part 1: Life cycle governance (Chapter 10, Well Abandonment Phase, pages 70-76). For abandonment wells, ISO mostly referred to NORSOK D-010, Rev. 4., 2013.

Oil & Gas UK (OGUK)

The OGUK Guidelines (Oil & Gas UK, 2015) provide the isolation of any permeable zones when wells are abandoned. This indicates that abandonment has the ability to isolate all penetrated flow potential zones (regardless of the fluid type) from the surface. Two barrier principles were further required in the abandonment philosophy (hydrocarbon and water-bearing zones), with the second concept acting as backup to the first. Moreover, the first concept should be set above or close to the highest point of potential inflow (top perforations), and also lapped by annular cement when placed inside a casing or liner. To be considered as a permanent barrier, the good cement length should be set at approximately 100 ft (30 m) in the casing or annulus. The OGUK Guidelines also considered that placing cement across perforations was often unnecessary.

Besides being the primary component, cement does not preclude the use of other materials towards meeting the standard requirements for permanent barriers. These requirements include very low permeability, long-term integrity, fluid resistance, etc.

NORSOK D-010

The NORSOK D-010 standard (Rev. 4., 2013, Well Integrity in Drilling and Well Operations, Chapter 9. Abandonment Activities, pages 81 – 110) from Norway was also reviewed in this study, due to being recently used and benchmarked in global oil and gas industries. In this case, well abandonment was performed based on integrity management barrier philosophy.

According to NORSOK D-010:2013 (2013), integrity is the application of technical, operational, and organizational solutions, to reduce the risk of uncontrolled fluid formations throughout the life cycle of a well. This indicates that all operations conducted during this life cycle should comply with the barrier philosophy. Furthermore, assurance is found to comply with barrier philosophy in well development, where two independent factors were installed to avoid leakages to the surface. It also creates "hat over hat" barriers to ensure or minimize the possibility of leakages.

NORSOK D-010:2013 (2013) further defined permanent abandonment as the inactive status of a well design, where risk assessment was performed to ensure proper method based on the hole data, i.e., sufficient annulus cement, as well as no casing pressure and milling requirements. Moreover, section milling was conducted to establish cement plugs and well barriers in the annuli. When the cement sheath did not show a minimum barrier of 30 m (poor formation/cement bonding), perforation was performed with a low-pressure squeeze as an external foundation. This was accompanied by further section milling performances, to expose the formation. In addition, primary and secondary cement plug formations were each set to 50 m in the casing.

NORSOK D-010:2013 (2013) also defined multiple reservoir zones/perforations within a similar pressure regime, where a primary and secondary well barrier was installed. Meanwhile, these barriers were individually confined when the zones had different pressure regimes. As a shared unit for more than one wellbore, the permanent well barriers should be vertically and horizontally secured and sealed, as presented in Figure 3.

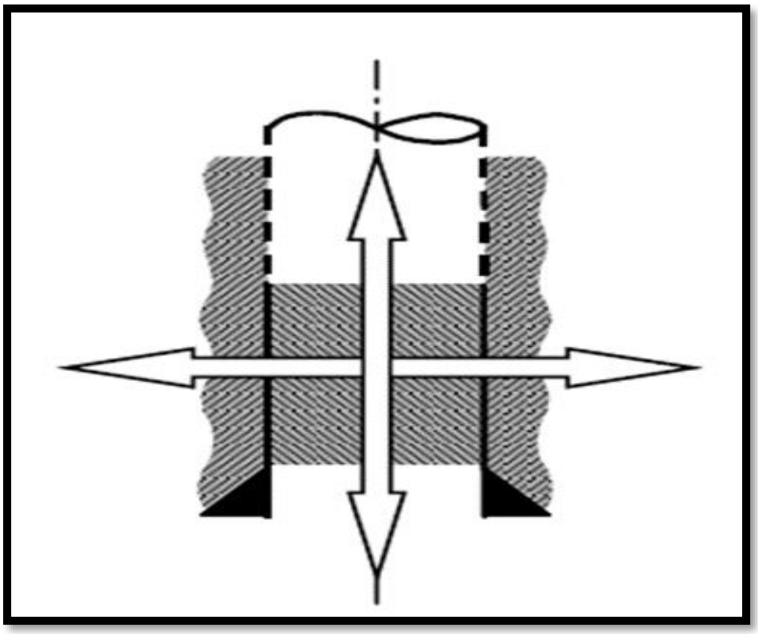

Figure 3. Permanent Barrier Illustration (Source: NORSOK D-010:2013 (2013))

RESULT AND DISCUSSION
Gap Analysis

Based on the literature research above, below are the gap analysis:

Table 1. Gap Analysis of Indonesia Well Abandonment Standard

No.	Strategic Objective / Requirement	Current Standing (SNI 13-6910-2002)	Gap Analysis

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1	**Abandonment Barriers Philosophy**	Prescriptive approach with specific height and length of cement plugs.	• Did not define the philosophy of abandonment barriers.
2	**Plugging/Isolating Materials**	Cement and KMW (Kill Mud Weight)	• Cement had some limitations and required longer operations. • Options on other plugging/isolation materials were not defined. KMW was not a barrier, as it settled after time due to temperature and pressure.
3	**Objectives Reservoir Isolation**	Open hole: The cement plug was minimally set at 100 ft, to isolate fluids below and above the top of any oil, gas, or freshwater zones. Perforated interval: All perforations were minimally set at a cement plug of 100 ft below and above the perforated interval.	• Ambiguity: Only perforated reservoirs or isolated open-hole were mentioned. Any other reservoirs with flow potential at similar/different pressure regimes in the upper sections were not mentioned. Several barriers were defined (Permanent Primary Barrier, Permanent Secondary Barrier). • Multiple zones/perforations located within similar pressure regimes were regarded as one reservoir that accommodated primary and secondary well barriers. However, the zone of primary and secondary barriers was individually confined when multiple perforations had different pressure regimes. • The barriers were created above the perforations.
4	**Intermediate Reservoir Isolation**	Not mentioned	• The intermediate reservoir isolations were not mentioned. Several barriers were defined (Permanent Primary Barrier, Permanent Secondary Barrier. • Multiple reservoirs/zone with flow potentials were elaborated.
5	**Annular Barriers**	The annular space communicating with an open hole and extending to the mud line was plugged at approximately 200 ft of cement.	• When the verification result on the cement was degraded/uncemented, the performance to regain annular barriers was not well defined. • What methods were used to isolate annular?
6	**Control Lines**	N/A	• Control lines were removed due to creating cement

		channels. • For control lines connected and cemented to the casing, the milling section was used to destroy, for barriers to be placed.

Abandonment Barrier Philosophy

All operations complied with barrier philosophy during the life cycle of the well, including the process of abandonment, where assurance correlated with philosophy. In this case, two independent barriers were installed to avoid leakages to another formation or the surface. Furthermore, Khalifeh & Saasen (2020), practically stated that an abandoned well should be equipped with two independent barriers (primary and secondary barriers or hat over hat principle). Based on these conditions, this aspect of the study focused on permanent abandonment barriers. In this aspect, reservoirs were often covered with cap rocks to prevent the flow of formation fluids to other zones or surfaces. These rocks were breached and replaced by cemented casings during the well construction. In addition, the cement with proper bonding (verified and documented) is known as a barrier. During the expiration of the lifecycle, the well is abandoned by placing permanent and secondary barriers to ensure no future leakage. Since the natural barrier was breached, several international regulations stated that the primary annular principle should be set by milling the casing section, to ensure proper cap rock sealing. Meanwhile, a primary barrier placed at a certain depth above the open perforations should be squeeze or covered, according to NORSOK D-010:2013 (2013).

Plugging/Isolation Materials

Cement is still the largest plugging/isolation material used for permanent abandonment. However, it has several limitations, with some studies such as Gasda et al (2004) mapping out its failure mechanisms through possible leakages. Moeinikia et al (2018), also showed that leakage through bulk cement, cracks, and micro annuli were caused by hydration processes and shrinkage factors that generated high tensile stresses. In addition, the casing is likely to become a leak path when the cement sheath is not properly bonded, leading to the penetration of CO_2, saline water, or H_2S that degrades construction strength.

Several studies and experiments were further developed to meet the abandonment standard materials, as mentioned by ISO *(ISO 16530-1:2017 - Petroleum and natural gas industries — Well integrity — Part 1: Life cycle governance*, 2017), Oil & Gas UK (2015) and NORSOK D-010:2013 (2013). These included long-term integrity, impermeability, non-shrinking, impact and chemical resistances, harmless and bonded to steels. These studies aimed to gain economical and efficient operations for compliance. Therefore, Vrålstad et al (2019) and Khalifeh & Saasen (2020) summarized the alternatives of plugging/isolation materials as follows,

Table 2. Brief descriptions of alternative plugging/isolation materials

Plugging / Isolation Materials	Brief Descriptions
Non-setting materials	Mostly unconsolidated sand slurries, bentonite, or barite plugs. Unconsolidated sand slurries are derived in two stages, namely 75 and 25% solid and liquid phases with PDS (particle size distribution) and conducting fluid (water, dispersant, and viscosifier), respectively. Even with high yield stress (difficult to pump), the slurry was unshrinkable and not set after placement. Hydrated bentonite plugs are applied for permanent abandonment, due to swelling ability and very low permeability. This was in line with field trials already performed in the USA (oil and gas wells) and Australia (coal seam gas, water wells), as mentioned by Towler et al. (2016). Barite plug is known to stop gas flow in well control drilling operations, due to being a slurry mixture of complex phosphate thinner (barite) and water (Messenger, 1969). The determination of the plug top through barrier verification is not applicable due to non-setting.

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	Mostly resins.
Thermosetting Polymers	Resins are particle-free fluids that turn hardened materials into impermeable components. Hardened time is often activated due to being temperature-dependent. These materials are globally used as plugging components for squeeze, casing leaks, annular pressure eliminations, etc. The studies of resins degradation with time (for long-term use) should be tested before operations, because of exposure to downhole chemicals and thermal decompositions.
	Mostly bismuth-based material.
Metals	The use of low melting point alloys, which creates a good metallic bond to the casing after the temperature-activated curing process. It has expanding capability (3:1) when solidified, no porosity, and gravity flow (no need for squeeze). Although barrier verification is difficult, this technology is considered a reliable plugging material (Fulks et al., 2019).
Gels	Polymer gels with water/gas shut-off capabilities are studied as plugging materials, as some of them created irreversible operations (Darmawan, 2020).
Geopolymers	Geopolymers are like artificial stones developed in civil constructions. The physical characteristics of fly ash formulations are verified and used as a cement substitute. They also provide a friendly and more economical method of plugging wells. Brine or acidified water does not damage the plug and are likely to withstand 500 psi compressive strength, as well as have fluid losses of 67-130 ml/30 mins.
Modified in-situ Material	The use of metal powder and oxide through the ignition of heat is known as Thermite. This is an exothermic reaction that melts all corresponding materials (casing, cement, formation), therefore producing an impermeable solid.

Objectives Reservoir Isolations

NORSOK D-010:2013 (2013) standard required two barriers and several fluid-bearing formations in the overburden. This indicated that overpressure and hydrocarbon zones should be isolated with two barriers. Primary and secondary barriers in the lifecycle of a well are not highly different from each phase (verified), except with an additional cement plug for the abandonment stage.

Intermediate Reservoir Isolations

Barriers in the intermediate sections should be set in front of a suitable cap rock, which is impermeable, laterally continuous, as well as adequately strong and thick (Diaz, 2017). It should also overlap annular cement (Diaz, 2017). The inventory of potential flow formations should be further prepared and reviewed to set the barriers.

Annular Barriers

Based on well integrity, Prasetya et al (2018) recommended the applications of Oil & Gas UK Guidelines (OGUK) and Standard National Indonesia (SNI). This was a good approach to quantify the annulus conditions before abandonment, to obtain a full cross-sectional barrier from rocks (Vrålstad et al., 2019; Norsok, 2013)

These annular conditions should be monitored and documented during the lifecycle of the well, to understand the leak paths, risk assessments, and remedial operations. One of the major causes of annular pressure was cement sheath failure due to age. Also, a cement evaluation log should be conducted for barrier verification. When the good cement length is less than normal, the barrier should be restored. In addition, the annular barrier restoration method is section milling and cement, PWC (Perforate-Wash-Cement), and in-situ formation activation. Figure 4 shows the annular barriers with section milling operations. Table 3 shows the description of annular barrier placement method.

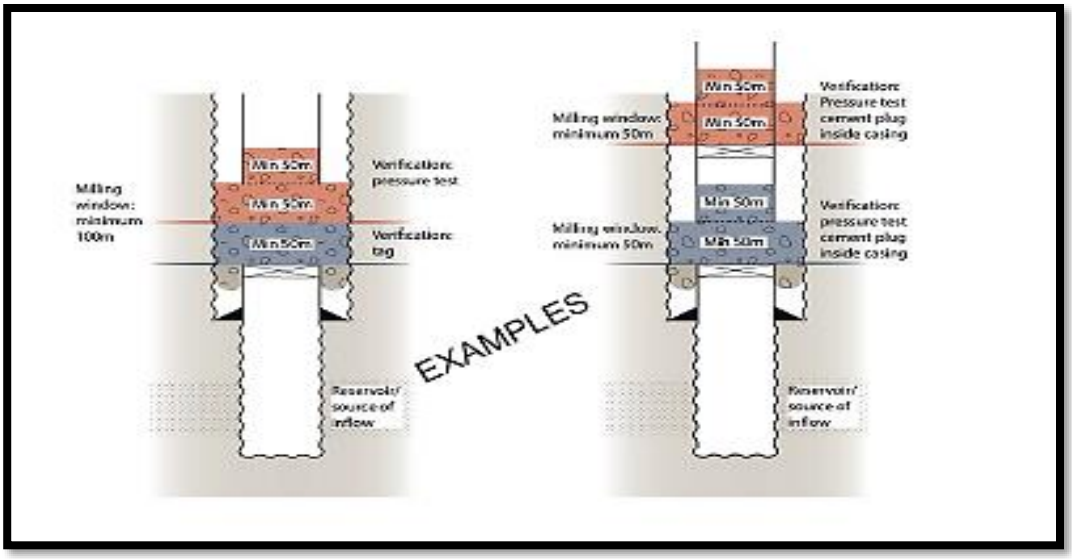

Figure 4. Permanent Abandonment, annular barrier with section milling (Source: NORSOK D-010:2013 (2013))

Table 3. Brief descriptions of Annular Barrier Placement Method

Annular Barrier Placement Method	**Brief Descriptions**
Section Milling and Cement	Section milling is a method to remove casing, cement, and mud debris. This is achievable when the casing is fully or partly cemented. It is also a time-consuming process that mostly creates operational problems due to the downward milling movement of the metal debris. In addition, the upward milling movement is developed by several service companies, to avoid operational problems.
PWC	This is a one-time operation involving the performance of perforation, washing off, and cementing. Delabroy et al. (2017) recommended EAC (element acceptance criteria) for the PWC method, due to being unlisted in the policy table within NORSOK D-010 Rev. 4, 2013. In a single operation, PWC created both annular and internal well barrier elements, which should be verified. Moreover, Vrålstad et al. (2019) used PWC when the annulus was uncemented or partly filled with poor cement.
Shale as annular barriers	Kristiansen et al. (2018) concluded that shale was activated as daily or hourly annular barriers by the rapid pressure drop in an annulus, water-based chemical process, and increasing temperature in the near-wellbore area. Barrier verification was further conducted using a cement bond log and pressure test. Furthermore, Vrålstad et al. (2019) and Khalifeh & Saasen (2020), mentioned that shale creep was a slow deformation dependent on temperature and differential stress, which filled up the annulus and impermeable (act as a barrier). In addition, swelling clays were not suitable for the plugging material.

Control Lines

Wells with control lines/cables were removed before setting any permanent plugs, due to creating a new leak path to the surface. For connected and cemented casing control lines, the use of section milling was carried out for degradation purposes before placing the barrier. Meanwhile, several studies should be performed to eliminate the leak potential with other types of plugging materials.

Discussions

The philosophy of barriers should be established in Indonesia's abandonment standard, as part of well technical design and operations (International Standards). Performance-based (functional-based) approach standard is also preferable to achieve proper objectives, as well as ensure that operating companies have broad technologies and techniques for permanent abandonment. In contrast to the

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prescriptive approach on law and regulations, operating companies should become passive and also provide the Indonesian government with potential environmental issues, leakages, etc. In addition, Darmawan (2021), proposed the use of Well Integrity Management (WIM), as part of assessing the wells before abandonment.

Based on these descriptions, future studies should emphasize the post abandonment surveillance or methods to ensure that methane emission does not reach the surface during the expiration phase.

CONCLUSION

Based on this literature study, several summaries were derived as follows,

- The gap analysis of Indonesia's abandonment standard showed some improvements opportunities in philosophy, plugging materials, objective and intermediate reservoir isolations, annular barriers, as well as control lines removal. These gaps provided a better perspective of eternal abandoned wells.
- Performance-based approach standards recommended that the operating companies should broaden permanent abandonment technology and techniques, to achieve a proper well objective. This approach further helped Indonesia to welcome abandonment waves.

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