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Through Tubing Well Abandonment:
Challenges and Possibilities

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Abstract

Well abandonment is crucial in the oil and gas industry, ensuring environmental safety and compliance as wells cease production. Through Tubing Abandonment (TTA) is an innovative approach that differs from traditional plug and abandonment (P&A) methods by allowing operations to be conducted through existing tubing, thereby eliminating the need for its removal. This method offers significant economic benefits and reduces Health, Safety, and Environment (HSE) risks.

This thesis examines the effectiveness, challenges, and possibilities of TTA. Through a comprehensive review of industry reports and a qualitative interview with a field professional, the study explores the operational efficiencies, cost savings, and technological advancements required for TTA. The findings demonstrate that TTA can lead to substantial cost reductions and time savings while maintaining well integrity and environmental safety.

Key challenges include the need for advanced logging tools and reliable cement placement techniques. The study highlights the potential of new sealing materials and improved logging technologies to overcome these barriers. Regulatory compliance and strategic planning are essential for optimizing TTA outcomes.

The conclusion synthesizes the research findings, providing a detailed overview of TTA's benefits and limitations. It also offers insights into TTA's future, emphasizing the importance of technological innovation and regulatory adaptation in enhancing well abandonment practices in the oil and gas industry.

Acknowledgment

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Terminology and Abbreviations

A-annulus - The space between the casing and the production tubing in a well.

ASV - Annulus Safety Valve, a valve that helps control the flow within the annulus.

BHA - Bottom Hole Assembly, the lower part of the drill string, including the drill bit and various tools.

CBL - Cement Bond Log is used to evaluate the integrity of cement jobs in a well.

CT - Coiled Tubing, a long, continuous steel pipe wound on a spool used in various well operations.

DHSV - Downhole Safety Valve, a valve installed in the production tubing of a well to control flow.

FEA - Finite Element Analysis, a computational technique used to predict how objects behave under various physical conditions.

HSE - Health, Safety, and Environment, a set of standards and practices designed to ensure the well-being of workers and the environment.

ICR - Inflatable Cement Retainer, a tool used to isolate sections of a wellbore during cementing operations.

KWV - Kill Wing Valve, a valve used to control well flow during kill operations.

LWI - Light Well Intervention, a method of performing well maintenance and interventions without traditional drilling risers.

LWIV - Light Well Intervention Vessel, a vessel used for performing light well interventions.

MD - Measured Depth, the wellbore length measured along the well's path.

NCS - Norwegian Continental Sector, the offshore area of Norway where oil and gas exploration and production occur.

NORSOK - The Norwegian petroleum industry's standardization organization develops standards to ensure safety and efficiency in petroleum operations.

NORM - Naturally Occurring Radioactive Material, materials containing radioactive elements found naturally in the environment.

P&A - Plug and Abandonment, the process of permanently closing a well to prevent the migration of fluids between subsurface formations.

PSA - Petroleum Safety Authority, the Norwegian government agency responsible for ensuring safety in the petroleum industry.

SCP - Sustained Casing Pressure, the pressure that persists in a well's casing annulus, indicates potential issues with good integrity.

STV - Standing Valve, a valve used to prevent backflow in a well.

TOC - Top of Cement, the highest point of a cement column in a well.

TTA - Through Tubing Abandonment, a method of well abandonment that involves performing operations through the existing production tubing.

WBE - Well Barrier Element, components used to create barriers to prevent fluid migration in a well.

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1. Introduction

What challenges and possibilities come with TTA?

The oil and gas industry plays a pivotal role in global energy supply, with wells serving as vital conduits for hydrocarbon extraction. However, as wells end their productive life or become uneconomical, proper abandonment procedures are essential to mitigate environmental risks and safeguard public safety. Plug and Abandonment (P&A) operations represent a critical phase in the lifecycle of oil and gas wells, ensuring the secure and permanent closure of boreholes to prevent the migration of fluids between subsurface formations. In recent years, TTA has emerged as a specialized technique within the realm of P&A, offering a cost-effective solution for decommissioning wells with integrity issues or complex downhole configurations.

1.1. Background and Motivation

Traditionally, P&A operations involved placing cement plugs across multiple casing strings to isolate hydrocarbon-bearing zones and prevent fluid migration. However, conventional P&A methods often entail significant time, cost, and logistical challenges, particularly in wells with deteriorated casing or extensive completion equipment. Through-tubing abandonment techniques have revolutionized well abandonment practices, allowing operators to circumvent obstacles within the wellbore and achieve isolation through smaller-diameter tubing strings or coiled tubing.

1.2. Research Objectives

Before delving into the specifics of TTA and its implications, it's essential to understand the broader context and significance of this topic in the oil and gas industry. TTA represents a novel approach to good abandonment, offering potential advantages over traditional plug and abandonment methods. However, implementing TTA poses various challenges and technical considerations that warrant investigation. In this study, I aim to explore critical aspects of TTA, ranging from its technical differences compared to traditional methods to the role of cementing in ensuring long-term well integrity. By addressing these research questions, we seek to deepen our understanding of TTA and contribute valuable insights to industry practices and knowledge.

This thesis aims to address the following research questions:

- How Through Tubing Abandonment Differs from Traditional Plug and Abandonment Methods
- The Most Common Challenges and Technical Barriers Encountered During TTA Operations
- What emerging technologies and innovations hold the potential to enhance TTA practices further?

1.3. Scope and Structure of the Thesis

In this thesis, I will begin with a theoretical section, followed by a methodology section, explaining how I conducted the interview. A results section, a discussion section, and a conclusion will follow. In the methodology section, I will present how I approached the interview and how the data was collected. I will describe the interview process and the rationale behind selecting the interview subject for this thesis. The results section will consist of a summary of the interview and the collected research. The discussion will involve comparing the theory with the results section. The conclusion will serve as a final summary, highlighting the answers I have obtained throughout the thesis concerning my research question.

2. Theory

This chapter presents the relevant theory for the thesis. This gives the reader insight and a better understanding of the thesis topic. The theoretical basis includes information about P&A, TTA, relevant concepts, and guidelines. With this information, I hope to create a suitable environment for discussion.

2.1. Regulatory on the Norwegian Continental Sector (NCS)

This section introduces the structured framework of regulations governing the Norwegian Continental Sector (NCS) and delves into specific mandates related to Plug and Abandonment (P&A) practices. The Petroleum Safety Authority (PSA) plays a pivotal role in overseeing the health, safety, emergency response, and working conditions of petroleum operations on the NCS. It crafts regulations and ensures adherence from stakeholders, including operators, contractors, and vessel owners. The sector hierarchy moves from laws, regulations, guidelines, standards, and internal company requirements (in that order). All petroleum operations must adhere to this regulatory landscape's established rules and guidelines. These regulations define the expected outcomes and standards companies must meet during operations without prescribing the methodologies to achieve these results. This approach allows companies to determine the most effective operational strategies, provided they meet the regulatory criteria. It fosters innovation by encouraging companies to explore and develop new technologies or methods. Furthermore, this regulatory model significantly reduces the necessity for the PSA to continually revise regulations in response to the dynamic technological advancements within the industry. [2]

2.2. NORSOK Standard

The NORSOK D-010 standard is a cornerstone of the Norwegian petroleum industry's efforts to harmonize well integrity protocols during drilling and operational activities. Originating as a concerted effort to streamline operational standards across the sector, NORSOK D-010 was designed to replace the myriad of individual company specifications with a unified set of guidelines. It specifically caters to the Norwegian Continental Shelf, establishing the baseline for well integrity. A pivotal aspect of NORSOK D-010 is its clear articulation of establishing Well Barrier Elements (WBEs) as critical components of well barriers, detailing their acceptance criteria and guidelines for their utilization and ongoing monitoring. Central to this standard is Section 3, which meticulously defines vital terms to eliminate any potential confusion. [1]

This delineation is crucial for ensuring clarity and compliance:

Shall: Denotes an obligatory action or requirement, implying a standard that admits no deviation for those claiming adherence to the document.

Should: Suggest a recommended action or condition, offering guidance without precluding other options.

May: Indicates permission or the possibility of taking a specific action.

Can: This word has a dual connotation: it can predict a likely outcome or affirm an entity's capability to meet a specified requirement.

By restricting these terms, NORSOK D-010 ensures its directives are clear and imperative, facilitating a shared understanding and application across the industry. This approach not only fosters a standardized practice for maintaining well integrity but also encourages innovation and the exploration of new methods within the framework of established guidelines. NORSOK D-010 casts well integrity as the strategic fusion of technical prowess, operational excellence, and organizational measures aimed at slashing the risk of formation fluids breaking free uncontrollably over a well’s entire lifespan. This spans the moment of a well’s conception to its final seal-off in a permanent plug and abandonment phase. Upholding well integrity at every phase of this journey is paramount. To avert leaks and mitigate hazards—thereby safeguarding well integrity—well barriers become indispensable. The crafting of these barriers, tailored to the unique demands of each well, hinges on a matrix of considerations, including the wellbore's geometry and state (addressing wear and tear and corrosion), along with variables like pressures, temperatures, and cement quality. A significant portion of NORSOK D-010 is dedicated to initiating and confirming well barriers by deploying Well Barrier Elements (WBE) and stringent acceptance standards to meet the goal of well integrity preservation.

2.2.1. Well Barrier

NORSOK D-010 articulates a well barrier as a protective shield comprising one or more well barrier elements that staunchly prevent fluids from inadvertently migrating from the formation into the wellbore, crossing into another formation, or escaping into the environment. At least one protective barrier must be established before drilling, completion, and P&A operations. However, two well barriers are mandated in cases where the potential inflow originates from a hydrocarbon-laden or abnormally high-pressure formation with the capacity to breach the surface. These are designated as the primary and secondary barriers, with the latter serving as a fail-safe in the event of the primary barrier's failure. Given that these barriers are the lone sentinels between the reservoir and the seabed surface, their ability to fulfill several critical criteria is essential. These include enduring all conceivable pressures and temperatures throughout the well's life, undergoing rigorous pressure and functionality testing, resisting the harsh marine environment, and ensuring that even if a barrier component fails, it does not result in any uncontrolled discharge of fluids or gases into the surroundings. Ideally, a well barrier is positioned as near as possible to the anticipated source of inflow to intercept all potential leak trajectories effectively. It is also tasked with establishing a vertical and horizontal seal to provide a comprehensive blockade. To uphold the integrity of this barrier, it's imperative to remove any downhole equipment like control lines, as NORSOK D-010 explicitly advises against incorporating control lines and cables into a permanent well barrier framework. [1]

2.2.2. Requirements

The NORSOK D-010 standard sets forth comprehensive requirements and criteria that must be met by well barriers, especially in the context of permanently abandoning a well. These criteria ensure that the abandonment process securely isolates the well, protecting the environment and the seabed from potential contamination or uncontrolled release of formation fluids. The standard delineates the roles and specifications of primary and secondary well barriers and the unique considerations for the open hole-to-surface plugs. [1]

Primary Well Barrier

The primary well barrier is critical in isolating potential sources of inflow, whether from formations with normal pressure or those that are over-pressured, from the surface or seabed. This barrier must be strategically positioned so its base lies at a depth where the integrity of the formation exceeds any potential pressure from below. This ensures that the barrier can effectively counteract forces that might compromise the well's seal.

Secondary Well Barrier

The secondary well barrier is a safety net that reinforces the primary barrier. It is a backup system designed to contain any source of inflow, mirroring the depth position of the primary well barrier. Its existence is pivotal in providing an additional layer of security, ensuring that even if the primary barrier were to fail, there would be no compromise in the well's integrity or an uncontrolled release of formation fluids.

Open Hole to Surface Plug

The open hole to surface plug plays a vital role in the permanent abandonment, especially after the casing(s) have been cut and retrieved. Its primary purpose is to block access to the well, containing any environmentally harmful fluids that may be present. It is particularly relevant in scenarios where the exposed formation is over-pressured but lacks a source of inflow and is devoid of hydrocarbons. Unlike the primary and secondary well barriers, the open hole-to-surface plug does not require a specific depth position for formation integrity. This acknowledges the different nature of the risks it addresses, focusing instead on securing—the well post-casing retrieval and ensuring environmental safety.

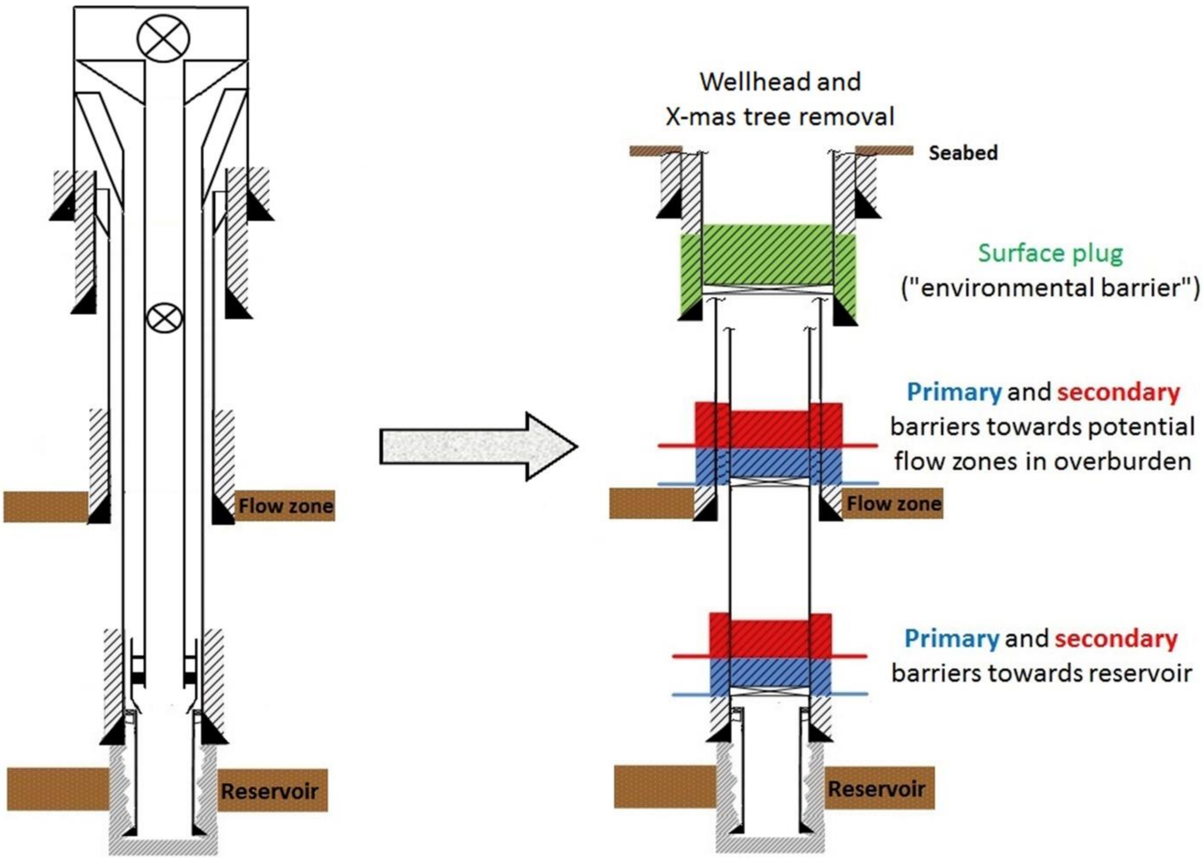

Figure 1 - Illustrates a typical well before and after a P&A operation [27]

In addition to this, NORSOK presents some requirements regarding the well-barrier materials.

Sustained Structural Reliability: Key measures of structural soundness, such as compressive strength, tensile strength, permeability, and Young's modulus, should consistently display no signs of decline over extended periods. Any indication of a negative trend warrants further investigation to identify a stable baseline.

Low Permeability Requirement: The material used for zonal isolation must exhibit water permeability of no more than five µD or less than 1000 times the permeability of the surrounding formation, whichever is higher. Alternatively, the isolation material must offer a barrier—concerning its permeability and length—that matches or surpasses the natural barrier capabilities of the original cap rock.

Radial Shrinkage Control: Open hole (OH) plugs or annular Well Barrier Elements (WBEs) should demonstrate minimal shrinkage to maintain integrity. In contrast, WBEs within cased holes should exhibit positive linear expansion over time to ensure lasting effectiveness.

Resilience to Mechanical Loads: WBEs subjected to forces beyond conventional knowledge or experience—such as those encountered in geothermal wells, injection sites, areas of significant resource depletion, or during high-pressure testing—must undergo Finite Element Analysis (FEA). To guarantee robustness, these elements should include a safety margin of 40% for each distinct load scenario.

Chemical Resilience: Without significantly compromising its structural integrity, the barrier material must endure exposure to potentially corrosive substances, including H2S, CO2, water, brines, and hydrocarbons. This ensures that the barrier remains effective throughout its intended lifespan.

Adequate Bonding to Tubular Structures: The material should form a secure bond with uncoated, cleaned steel or other tubular components where necessary. If direct bonding isn't feasible, the material must possess an alternative mechanism, like expansion, to maintain a hydraulic seal against the casing and any adjacent formation.

Compatibility with Tubular Materials: The barrier must not adversely impact the mechanical properties of any tubular structures it contacts, preserving the overall structural integrity of the system.

2.2.3. WBE Acceptance Criteria

The specific requirements for Well Barrier Elements (WBEs), as laid out by NORSOK D-010, are critical for ensuring the long-term integrity and safety of wells in the petroleum industry. These requirements are meticulously defined to cover external and internal barriers, with distinct specifications for their verification, placement, and length to manage the risks associated with drilling and well operations effectively. [1]

External WBEs:

For external WBEs, such as casing cement, NORSOK D-010 specifies:

- An external barrier must be considered permanent if it covers at least 50 meters with assured formation integrity at the base of the interval.
- If verified by logging methods that demonstrate acceptable bonding between the cement and formation and cement and casing, a length of 30 meters may suffice. Importantly, this 30-meter criterion can be met through aggregated smaller intervals within a logged section as long as the total equals or surpasses 30 meters.

Internal WBEs:

Regarding internal WBEs, primarily cement plugs, NORSOK D-010 provides detailed guidelines for their placement and required lengths, which vary based on well configuration:

- Open-hole cement plugs must extend 100 meters in Measured Depth (MD), including a minimum of 50 meters MD above any potential source of inflow or leakage.
- Cased hole cement plugs require a minimum length of 50 meters MD when set on a mechanical foundation or another cement plug. Without such a foundation, the requirement extends to 100 meters MD.
- Open hole to surface plugs need to be 50 meters MD if set on a mechanical plug. Without a mechanical plug, the length requirement increases to 100 meters MD.

These specifications underscore the importance of verifying and strategically placing WBEs to ensure that each internal or external barrier fulfills its role in preventing uncontrolled fluid migration and maintaining integrity.

2.3. Plug and Abandonment (P&A)

Plug and Abandonment (P&A) represents the final chapter in the operational life of oil and gas wells, a process integral to the responsible management of hydrocarbon resources. This procedure marks the cessation of production and embodies the industry's commitment to environmental conservation and regulatory adherence. The P&A process entails meticulously planned steps, including decommissioning well equipment, strategically placing cement plugs to isolate productive zones securely, and cutting the well casing beneath the surface to prevent future environmental or safety risks. The overarching goal of P&A is to permanently seal off wells from the surrounding strata, safeguarding against the escape of hydrocarbons and protecting water aquifers. As the energy sector faces increasing scrutiny regarding its environmental footprint, the methodologies employed in P&A operations have garnered significant attention, evolving to meet the dual challenges of operational efficiency and sustainability. This evolution reflects broader industry trends towards more sustainable practices, underscoring the critical role of P&A in the lifecycle of wells and its contribution to the legacy of the oil and gas industry in a changing environmental and regulatory landscape. [2]

2.3.1. Different Abandonments

The NORSOK D-010 standard outlines various stages in a well's life, including suspension and temporary and permanent abandonment. Each serves distinct purposes within the lifecycle of oil and gas exploration and production activities. [2]

Suspension:

This is a temporary state in which a well is not currently used but may be re-entered for future operations. The suspension can be for operational reasons, such as waiting for further development decisions, or due to technical issues that require resolution at a later stage. The well is secured to ensure it can be safely left without operations yet allows for the eventual resumption of activities.

Temporary Abandonment:

This involves a more extended period of inactivity beyond the typical operational pauses in suspension. In temporary abandonment, the well is sealed with more durable barriers, reflecting an intention that the well will not be used for an extended period. However, the well could be brought back into production or used for other purposes in the future. Temporary abandonment measures are reversible, albeit with more effort and cost than ending a suspension.

Permanent Abandonment:

This is the final stage of a well's lifecycle. It involves the complete and irreversible closure of the well. Permanent abandonment procedures ensure that the well poses no future environmental or public health risk. This includes the placement of permanent plugs to seal the wellbore, cutting the well casing below the surface, and restoring the site as close to its original condition as possible. The goal is to leave no potential pathways for the migration of fluids between underground formations or to the surface.

2.3.2. Operation Phases

Well abandonment is a structured process involving several operational phases. Each phase ensures that oil and gas wells are safe and effective decommissioning. This section will examine the critical operational phases, including preparatory work, reservoir abandonment, intermediate abandonment, and surface infrastructure removal. By understanding these phases, readers will gain insight into the systematic approach used to decommission wells. [27]

Phase 0

Phase 0 involves critical preparatory work essential for ensuring the smooth execution of the abandonment operation. Activities in this phase include retrieving tubing hanger plugs, which seal the tubing hanger, and killing the well to ensure it is safe for further operations. A deep-set mechanical plug is also installed to provide initial isolation within the wellbore. Punching or perforating the tubing allows for the circulation of fluids to clean the well, removing any debris or contaminants that may hinder subsequent operations.

Phase 1

Phase 1, also known as reservoir abandonment, marks the commencement of physical abandonment operations. The first step is rigging up the Blowout Preventer (BOP) to ensure well control during subsequent activities. The tubing hanger and tubing are then retrieved from the well, allowing access to the reservoir section. Here, the primary focus is establishing robust barriers to prevent hydrocarbon migration. The primary barrier is installed with its base at the top of the influx zone, effectively sealing off the reservoir. A secondary barrier is also installed strategically to withstand future pressures, ensuring long-term integrity.

Phase 2

Intermediate abandonment, represented by Phase 2, targets zones above the main reservoir but below the surface casing. This phase may necessitate the removal of casing strings to facilitate barrier installation. Primary and secondary barriers are installed to isolate potential flow zones in the overburden, mitigating the risk of fluid migration. A surface plug, commonly called the "environmental barrier," is installed to enhance well integrity and further environmental protection measures.

Phase 3

Phase 3, the final stage of the abandonment process, involves physically removing surface infrastructure to ensure site safety and environmental compliance. Conductor and casing strings are cut below the seabed to prevent interference with marine activities. Subsequently, casing strings, conductor, and the wellhead are retrieved from the wellbore and appropriately disposed of, finalizing the abandonment process.

2.3.3. Operation Procedure

There are multiple techniques for abandoning wells, each tailored to the specific construction and design of the well, with the overarching aim of installing barriers that effectively seal the well both vertically and horizontally, as specified in the NORSOK D-010 standard. Each well requires a distinct P&A procedure, though specific common steps are typically followed. [26]

Here’s a condensed outline of the essential steps in a standard P&A process:

Preparation for P&A:

First, a vessel or rig is positioned at the site of the well. The wellhead and the XMT are checked to confirm they are operational and safe. A wireline unit is set up on the platform and tested to ensure it meets safety standards.

The wireline unit conducts runs to assess the wellbore's condition and collects data such as tubing diameter and the presence of damage, scale, and corrosion.

Well Killing:

To deactivate the well, a dense fluid known as kill fluid is injected to elevate the hydrostatic pressure above the pressure within the formation, stopping fluid flow into the wellbore.

Removing Production Tubing:

The production tubing is severed above the production packer using a wireline, and the annulus and tubing are filled with kill fluid to check for proper circulation. This step is crucial for accessing the 9 5/8" production casing to inspect and evaluate the condition of the cement behind it, which is essential for determining where to place the cement plug barrier.

Installing Barriers:

Barriers are installed to isolate the reservoir fully. The number and type of barriers depend on the number of potential inflow sources. Logging tools assess whether the casing cement is adequate for an internal cement plug or if methods such as section milling or the perforate, wash, and cement (PWC) technique are necessary.

Surface Plug Installation:

A surface plug is set within the 13 3/8" casing unless there is potential for gas flow from other annuli. This would necessitate further investigations and cementing actions to ensure a robust cement barrier across larger casing diameters.

Final Removals:

The process concludes with cutting and removing the conductor, casing strings, and wellhead, which are removed a few meters below the seabed to ensure the well is permanently sealed off.

These steps ensure the well is safely and environmentally secure, with robust barriers to prevent leaks.

2.4. Through Tubing Abandonment (TTA)

TTA is a sophisticated and increasingly crucial technique in the oil and gas industry to ensure the safe, environmentally friendly, and cost-effective closure of non-productive or end-of-life wells, especially in offshore environments. As global emphasis on environmental sustainability intensifies, the oil and gas industry faces significant pressure to improve its operations' safety and environmental soundness. TTA emerges as a pivotal response to these challenges, offering a method that leverages existing well infrastructure to mitigate risks and reduce the ecological footprint of abandonment operations. TTA is distinct because it utilizes the existing production tubing to deliver abandonment materials—primarily cement—to critical points within the well. This approach circumvents the conventional necessity to remove extensive downhole equipment, which is technically challenging and time-consuming and poses considerable environmental risks and economic burdens. By maintaining the tubing in place and using it as an integral component of the abandonment process, TTA simplifies the entire operation, enhancing its efficiency and safety. The development of TTA reflects a broader industry trend towards innovative technologies that conform to stringent regulatory standards and align with global environmental conservation goals. In offshore settings, where traditional abandonment methods can significantly disrupt marine ecosystems and entail hefty logistical costs, TTA presents a minimally invasive alternative that can be executed with markedly lower impacts on the surrounding environment. [5]

2.4.1. Concept of TTA

Through Tubing Abandonment (TTA) is emerging as a preferred method for well decommissioning, primarily for its contributions to Health, Safety, Security, and Environmental (HSSE) considerations. This technique minimizes the need for suspending wells and setting up drilling blowout preventers, typically required to extract completion equipment. By leaving the tubing in the well, TTA notably reduces the hazards associated with handling and processing the tubing at various stages, from extraction by rig personnel to transportation and eventual disposal. For instance, decommissioning a well with a 10,000-foot completion traditionally involves removing and handling approximately 250 tubing joints. Each step introducing potential safety risks must be transported for recycling or disposal. By eliminating this process, TTA significantly reduces person hours and the likelihood of safety incidents. Moreover, it prevents exposure to Naturally Occurring Radioactive Material (NORM) when such contaminants are present, avoiding the need for specialized cleaning and disposal protocols. Environmental considerations extend beyond direct handling to encompass transportation impacts. TTA permits using more environmentally friendly alternatives for abandonment operations, such as Light-Weight Intervention Vessels (LWIV) and smaller rigs, which require less operational time. These alternatives reduce greenhouse gas emissions compared to the larger rigs required for conventional abandonment. TTA is appropriate for a subset of wells that meet specific architecture, integrity, and platform requirements. Screening for potential TTA candidates involves reviewing the historical performance of primary cement work, especially in the absence of cement bond log data. This review helps ensure the robustness of the annular cement isolation—a crucial aspect of TTA. Other selection criteria include sustained casing pressure, accessibility, and potential obstructions within the tubing. A detailed risk assessment follows the candidate screening, evaluating the probability of seepage and confirming the cement plug's ability to provide sufficient long-term isolation. This assessment takes into account all possible leak paths and their potential flow. Modeling techniques can offer further assurance, simulating the long-term effectiveness of the TTA and informing the design of the cement plug length required for enduring isolation. [5]

2.4.2. Selection Criteria

This chapter details the selection criteria used to determine the suitability of wells for TTA, which are crucial for ensuring the safe and effective isolation of hydrocarbon-bearing formations. [5]

1. **Challenges with Sustained Casing Pressure in Production or Intermediate Casings**
   Sustained Casing Pressure (SCP) suggests a breakdown in cement isolation, potentially disqualifying a well from TTA using existing technology. Nonetheless, SCP might not bar TTA for a lower isolated flow zone if the SCP's origin is shallow, where lead cement provides weaker isolation than tail cement. It's essential to pinpoint the source accurately, possibly through isotopic analysis or thermal/acoustic logging.
2. **Integrity of Casing or Liner Annuli at Barrier Levels**
   The casing and liner annuli must be properly cemented at the depths of the barrier/caprock to ensure necessary isolation. While Cement Bond Log (CBL) validation may not be required with reliable post-job data, re-evaluating original cementing jobs could improve limited historical data. If the casing or liner is poorly cemented, proceeding with TTA is not an option. Other methods to check cement integrity include punching and testing in adjacent wells (not via tubing) and advanced logging methods after making the tubing accessible.
3. **Access Issues Due to Tubing Blockages**
   Obstructions within the tubing, like debris, scale buildup, or structural damage, can restrict access to crucial barrier depths, thus complicating well suspension operations. Such situations might necessitate the removal of the tubing.
4. **Presence of Deep Lines at Barrier Depths**
   No lines should intersect the isolation interval or caprock, although their presence doesn't necessarily rule out TTA. Detailed risk assessments of potential leaks and the degradation of line materials are essential.
5. **Impact of Annulus Safety Valves (ASV)**
   An ASV can restrict the flow needed for adequate through-tubing circulation and cementing. TTA may only be possible with possible corrective measures.
6. **Positioning of Packer Relative to Barrier Depth**

The packer should be positioned a minimum of 100 feet measured depth below the lowest barrier depth for optimal well barrier integrity. If barriers need to be set below the production packer, they might require removal or milling unless they are accessible by coiled tubing.

7. **Constraints of Site/Platform/Subsea Tree for Operations**

   Offshore platforms or subsea trees may need more infrastructure like loading capacity, deck space, or crane operations to support rigless operations, potentially requiring additional support vessels.

8. **Isolating Multiple Reservoirs**

   Isolating several reservoirs is often feasible with Coiled Tubing. Through-tubing methods can isolate intermediate flow zones with viscous reactive plugs to support annular cement or by setting extensive cement plugs that ensure isolation quality.

9. **Tubing Complications Due to Leakage**

   Leaks in the tubing, possibly from corrosion or attachments, prevent its use for cement pumping. Solutions include accessing with Coiled Tubing or fitting a patch, assuming it doesn't complicate the TTA process. Components like gas lift valves might also create leakage paths.

10. **Challenges with Inclinations Above 60 Degrees Near Packer**

    Steep inclinations more significant than 60 degrees may prevent wireline operations necessary for setting plugs and modifying tubing, possibly requiring Coiled Tubing or tubing extraction.

11. **Overall Well Integrity Assessment**

    A final review to confirm the well’s structural integrity and operational readiness is crucial before proceeding with any operations.

After the well has been assessed as a possible candidate for TTA, a risk assessment will be conducted to confirm that the candidate's cement plug is qualified for isolation regarding ALARP. Figure 2 depicts examples of said assessment.

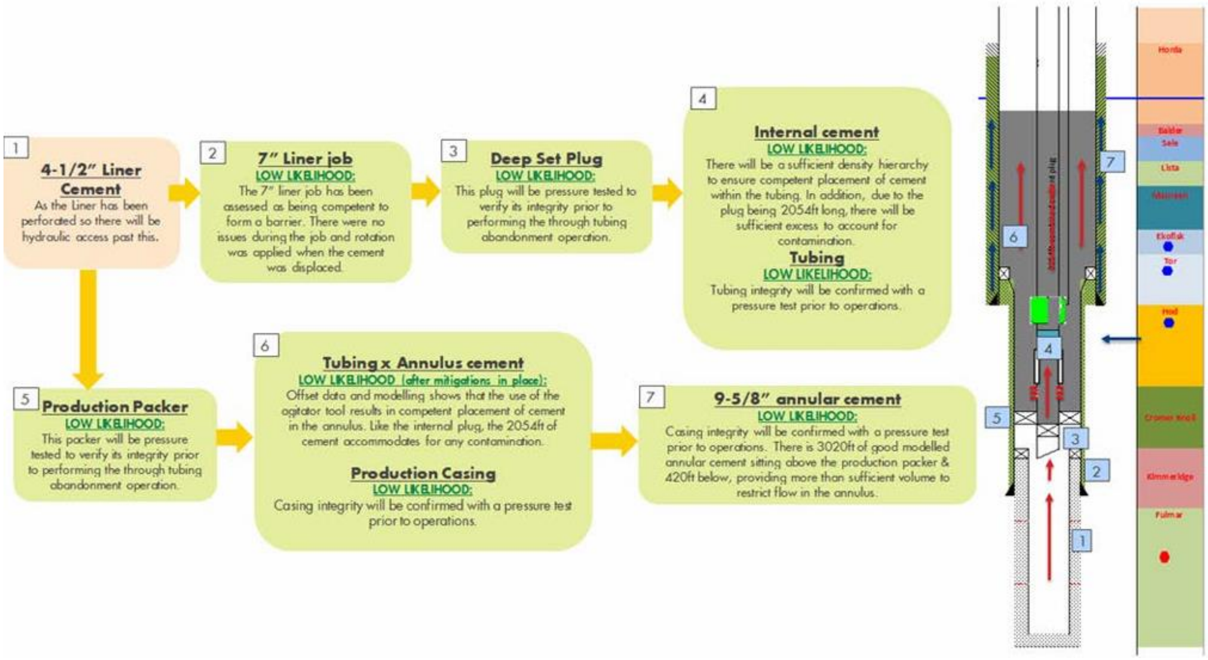

Figure 2 - Example leak path assessment [5]

2.4.3. Operation

Through Tubing Abandonment (TTA) is a critical operation in the oil and gas industry, enabling safe and efficient well decommissioning. This chapter details the TTA procedure, a series of systematic steps designed to securely seal off a well while minimizing safety risks and environmental impacts. The process leverages existing well architecture to place permanent barriers, eliminating the need for extensive tubing retrieval and handling. By detailing each operational stage—from initial setup to the final verification—this chapter provides a concise, step-by-step guide to the TTA methodology. [5]

Initial Setup:

Connect to the Kill Wing Valve (KWV) or an appropriate connection point on the Christmas Tree to create a setup barrier.

Cement Line Installation:

Install a dedicated 2-inch cementing line from the cement system directly to the Master Kill Wing Valve (MKWV). Confirm that this setup can manage return flows from the well annulus during simultaneous operations.

Line Testing:

Conduct a pressure test on the cementing line at 250/3,000 psi for 5-minute intervals. Monitor the volume carefully during the test to ensure the Christmas Tree valves are functioning correctly and not leaking.

Preparation Meeting (Toolbox Talk):

Discuss and verify all pre-circulation checklist items, including contingency plans for handling issues during the cement job. Check the readiness of the spacer, review the line setup for the cement operation, and ensure all participants understand the process.

Cementing Process Setup:

Arrange for the cement pumped from the unit through the dedicated line to the MKWV and into the production tubing. Ensure that the high mobility valve (HMV), low mobility valve (LMV), and downhole safety valve (DHSV) are open while keeping the swab valve and production wing valve (PWV) closed.

Managing Returns:

Set up to collect returns from the A annulus through the intervention manifold into a containment pit.

Fluid Circulation:

Circulate one complete volume of seawater (519 barrels) at the optimal rate to condition the well before cementing.

Cementing Operation:

Execute a TTA with the following steps:

Pump 30 barrels of 12.0 ppg spacer,

Followed by 127.4 barrels of a 15.5 ppg expansive cement mixture,

Continue with 16.1 barrels of 12.0 ppg spacer,

Displace with 213.2 barrels of seawater, decreasing the rate to 2 per minute for the last 10 barrels to control hydrostatic pressure during the final displacement.

Maintain a rate of 3 barrels per minute throughout the cement and spacer pumping stages.

Note: This will result in an under displacement of 5 barrels, including a 3-barrel line volume to the tree.

Store at least one cement sample in the logging shack oven and one in the DSV office for reference.

Post-Cementing Actions:

Once cementing is complete, open a bleed port upstream of the MKWV to check for a vacuum in the well. Monitor how the cement settles. If the cement job is unsuccessful, do not circulate it out but set it as a balanced plug.

Documentation and Monitoring:

After cementing, document the tubing head pressure and pressures in annuli A and B. Allow the system to equilibrate so the cement can stabilize. Complete and sign the "Cement Plug Execution Checklist." Waiting for the cement to set further is unnecessary if the mechanical tubing plug is verified and the cementation checklist is complete without problems.

Final Steps:

Once the cement has stabilized, verify that the tubing and A annulus are filled to the surface, and then close the well. Begin flushing the cement line to ensure it is clear of any residues.

2.5. Concepts

This section of the thesis provides a comprehensive overview of the fundamental concepts and technologies that form the cornerstone of the study. It focuses on specialized areas and maritime operations in the oil and gas industry. An in-depth understanding of these concepts is crucial for analyzing the technological advancements and operational efficiencies that characterize modern energy extraction and maritime safety.

2.5.1. Coiled Tubing

Figure 3 - Coiled Tubing Setup on the Well [7]

Coiled tubing (CT) is a crucial technology in the oil and gas industry, offering a versatile and efficient means of well intervention and drilling. This detailed examination will explore the features, benefits, and specific uses of coiled tubing in modern petroleum engineering. [7]

Overview of Coiled Tubing Technology

Coiled tubing refers to a long, continuous pipe wound on a large reel. This allows it to be inserted into and extracted from a wellbore without needing to connect and disconnect pipe lengths. This method is essential for performing various tasks in vertical and horizontal wells.

Composition and Manufacturing

Coiled tubing is made from a high-strength steel alloy that provides flexibility and durability. It is manufactured from flat steel plates rolled and welded into a tube, then spooled onto a large reel. The tubing's coiled nature allows it to bend around the drum core without fracturing, although it does sustain permanent deformation from this bending, causing a slight curve when unspooled.

Deployment and Operations

During operations, the tubing is unspooled from the reel using an injector system mounted at the wellhead. This system controls the speed and tension of the tubing as it is fed into or pulled out of the well. The process is efficient and allows for rapid deployment compared to traditional pipe.

Applications of Coiled Tubing

Coiled tubing is used for a wide range of activities, including:

Well Maintenance and Cleaning: Acid stimulation is used to enhance the permeability of reservoir rocks, and washing is used to remove buildup and obstructions.

Drilling Operations: Although less common in regions like the Norwegian Continental Shelf, coiled tubing drilling has been used in projects abroad and for experimental operations in Norway during the 1990s.

Well Completion and Stimulation: Coiled tubing efficiently performs perforation, fluid injection, and gravel packing tasks.

Fishing Operations: Retrieving lost or stuck equipment from the wellbore.

2.5.2. Wireline

Wireline operations are essential in the oil and gas industry and crucial in well-maintenance, logging, and intervention. This comprehensive examination explores the intricacies of wireline operations, detailing their importance, methods, and safety protocols. [8]

Types of Wireline Operations

Wireline, or cable operations, involve using specialized cable systems to perform various tasks within a well. These operations are categorized based on the cable used and the specific requirements of the task:

Slickline Operations: A slickline is a thin cable used for straightforward tasks like opening and closing valves or setting and retrieving plugs. It offers simplicity and efficiency in light interventions.

Braided Wireline: This robust cable is employed for heavier interventions such as fishing (recovering lost tools), perforations, and mechanical manipulations. Its strength and flexibility make it ideal for demanding tasks.

Electric Line Operations: An electric wireline is a choice for real-time data transmission during interventions like logging or reservoir evaluation. It allows operators to monitor and adjust the operation based on live data from the well.

Operational Phases

Wireline operations are integral throughout the life of a well, from exploration to decommissioning:

Exploration and Drilling Phase: Logging tools are lowered into the well to evaluate potential reservoirs and formations. This data is critical for planning the well's development.

Production and Maintenance Phase: During production, wireline tools are used for tasks like logging to monitor reservoir performance, maintaining well integrity, and manipulating downhole equipment to optimize production.

Decommissioning Phase: Finally, in the decommissioning or abandonment phase, wireline operations are crucial for placing permanent plugs in the well, ensuring environmental safety and regulatory compliance.

2.5.3. Light Well Intervention

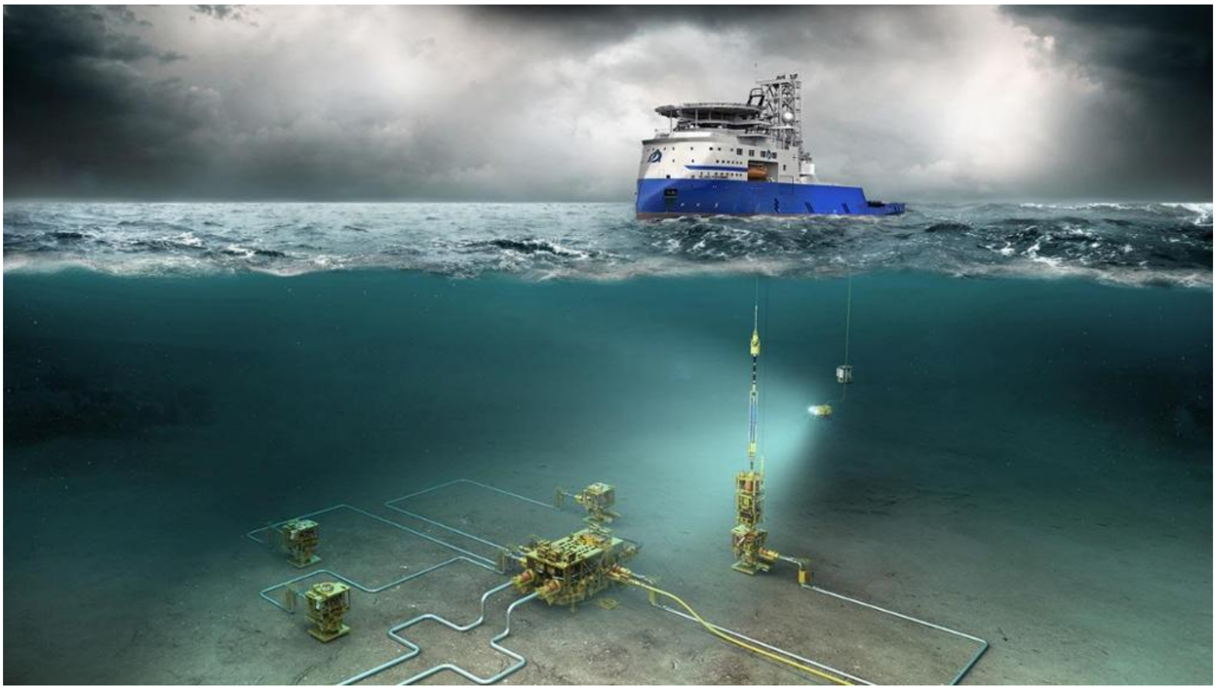

Figure 4 - Depicts a LWI with an LWIV [9]

Light Well Intervention (LWI) represents a significant advancement in the maintenance and servicing of subsea wells. This method offers a rapid and cost-effective alternative to traditional rig-based interventions by utilizing specially designed ships and well-controlled equipment. Here, we explore the innovations and operations involved in LWI, which streamline well-maintenance processes and reduce operational downtimes. Light Well Intervention (LWI) conducts well operations such as maintaining and repairing subsea wells without traditional drilling risers. This approach utilizes a specialized vessel and directs well-access technology to perform previously dependent tasks on larger, more cumbersome offshore rigs. [9]

Technologies and Equipment Used in LWI

Vessels: The ships used for LWI, known as Riserless Light Well Intervention Vessels (RLWIV), are smaller than traditional drilling ships and feature a design akin to supply vessels. These vessels have dynamic positioning systems to maintain accurate locations above the well without anchoring, allowing for precise operations.

Well Control Equipment: At the heart of LWI operations is the well control system that includes a deployment tower, moonpool for deploying tools, and various cranes for moving equipment. This setup enables wireline (WL) and coiled tubing (CT) technologies without the traditional riser.

LWI can be used for a variety of well interventions, including:

- Removing scale from production tubing
- Installing and retrieving well plugs
- Replacing downhole safety valves (DHSV)
- Logging production data
- Perforating well liners
- Stimulating reservoirs
- Detecting and repairing leaks
- Managing gas lift valves and removing sand from the production tubing

3. Methodology

This chapter details the approach used to address the research question. The thesis delves into TTA in the oil and gas industry, examining foundational theories and practical implementations. Data collection has been primarily conducted by interviewing an industry expert and reviewing publications. The thesis explores the operational efficiencies and environmental implications of utilizing TTA methods in contrast to traditional plug and abandonment techniques.

The data collection strategy was designed to enhance understanding of TTA, addressing the complexity and technical intricacies involved, such as the integrity of cement barriers and the execution challenges of performing abandonment through existing tubing. A qualitative approach was employed to gather detailed insights about specific procedures and technologies used in TTA. This included investigating common field challenges and industry leaders' methods to address them.

Interviews with an expert from Aker BP yielded crucial insights into TTA processes, the technologies utilized, and the safety measures implemented. These discussions also illuminated the industry standards and regulations that govern TTA practices.

The learning curve has been steep, with a comprehensive understanding of TTA practices, challenges, and safety considerations in the oil and gas sector developed relatively quickly. This chapter presents the chosen methodology, the procedures followed, the sources consulted, potential sources of error, and the analytical approach employed to synthesize the data collected.

3.1. Qualitative Method

The choice of method is based on the most suitable way to gather information. Qualitative methods, such as interviews, allow us to delve into depth and provide flexibility in our task. This has given me direct contact with the field and a better understanding of how to address my research question. [25]

To use the qualitative method correctly, several norms must be followed:

- The results should be consistent with reality. In practice, the results may contradict the study's assumptions. This must be accepted, as it is more important for the truth to emerge than for us to be correct.

- The data should be accurate. We should collect as precise data as possible during collection. The results should be as independent as possible of the person conducting the study. The idea is for a researcher to achieve the same result by following the same method.

- The researcher's preconceptions should be clarified. We always bring our biases, also known as preconceptions, into the study. This means we already have formed an opinion about the subject before starting the survey. It is easy to be influenced to see only what confirms our preconceptions. We should look for evidence that refutes our preconceptions to counteract this effect.

- The results should be checkable. The norm states that presenting the results should allow for control, verification, and criticism. Everything relevant to how others will assess the study should be included.

- The research should be cumulative. This means the method builds on existing research, such as previous studies or reports. Often, the research question chosen can build on existing research.

3.2. Publications Analysis

Publications play a vital role in enriching academic research, providing empirical evidence that helps to explore complex issues in a real-world context. They are precious in the context of a thesis investigating the nuances of Through Tubing Abandonment (TTA) compared to traditional Plug and Abandonment (P&A) methods in the oil and gas industry. They serve several critical functions that directly contribute to answering the research questions posed.

Justification for Using Publications

Illustrating Practical Applications: Allowance for a deep dive into the practical implementation of TTA methods across different geological and operational environments. This aligns with the thesis objective of understanding how TTA differs from traditional P&A methods, providing a grounded perspective that theoretical research alone cannot offer.

Identifying Advantages and Limitations: By examining specific instances of TTA, publications can highlight distinct advantages or reveal limitations in real-world settings. This empirical approach supports questions concerning the key benefits and limitations of TTA by presenting evidence from actual operations.

Exploring Challenges and Solutions: Publications detail real-world scenarios that expose common challenges and technical barriers encountered during TTA operations. They also showcase innovative solutions or adaptations made in the field, contributing significantly to the thesis section, which seeks to identify potential enhancements for efficiency and safety in TTA.

Contribution to Thesis

The carefully selected publications contribute substantially to the thesis by grounding theoretical discussions in empirical evidence and real-world practice. This approach enhances the reliability of the findings. It enriches the analysis with practical insights crucial for stakeholders in the oil and gas industry considering TTA for well abandonment. Using publications helps construct a robust argument addressing the thesis's central question, whether TTA provides a safe and effective solution for abandoning oil and gas wells, supported by real-world data and examples.

3.3. Choice of Topic

The selection of TTA as the topic for a bachelor thesis is driven by its critical role and innovative potential in enhancing well abandonment practices within the oil and gas industry. This method offers notable advantages such as reduced operational costs, minimized environmental impact, and enhanced safety, making it a highly relevant study area as the industry progresses towards more sustainable practices.

TTA techniques are particularly pertinent in the current landscape because they allow for the abandonment of wells directly through existing tubing, bypassing the need to remove the tubing beforehand. This efficiency in procedure significantly reduces the time and resources required for abandonment operations, aligning with the industry's goals of cost-effectiveness and environmental responsibility.

Additionally, with stricter regulatory demands and an increasing focus on environmental stewardship, the oil and gas sector faces considerable pressure to adopt practices that ensure the integrity of decommissioned wells and prevent environmental contamination. TTA presents a compelling solution to these challenges, providing robust barriers that effectively seal off and isolate abandoned well sections.

Interest in this topic also stems from the technical challenges and innovative solutions associated with TTA. The complexity of achieving reliable seals through existing tubing presents intriguing engineering challenges. Exploring these issues and the latest advancements in materials, techniques, and regulations enriches academic discourse and is highly relevant to advancing industry practices.

Focusing on TTA in a thesis can contribute significantly to developing best practices in well abandonment, strongly emphasizing sustainability and safety in oil and gas operations. This research could deepen the understanding of well abandonment processes and provide specialized knowledge that is increasingly valuable in the industry.

3.4. Use of Sources

In conducting research for this thesis, meticulous attention was devoted to gathering data from respected sources renowned for their contributions to the oil and gas industry. OnePetro, an extensive online library managed by the Society of Petroleum Engineers (SPE), has been mainly instrumental. This repository is a treasure trove of scholarly articles, technical papers, and conference proceedings that delve into advanced practices in well abandonment, including TTA methods.

An engineer with first-hand experience with tubing abandonment operations was interviewed. This professional affiliated with Aker BP offered practical insights and validated various technical approaches discussed in the academic and industry literature.

These sources, enriched by practical field data and theoretical research, form a comprehensive foundation for exploring the viability, challenges, and advancements in TTA. This ensures a well-rounded thesis that reflects the current state of technology and addresses the industry's push toward more sustainable and safer oil and gas extraction methods.

3.5. Interview

The interview conducted for this research was qualitative and carried out using mail exchanges. An interview guide was shared with participants beforehand to introduce the procedures, the focus of the discussion, and the questions to be answered in the interview. Before the interview, approval was obtained to ensure all privacy concerns were addressed appropriately.

Obtaining consent not only met legal requirements but also enhanced the professionalism of the project, thereby increasing its credibility. This process also provided the participant a secure environment to discuss various topics openly.

3.5.1. Interview Object

In this thesis, the interview object is an expert in their field. They bring diverse experiences concerning the subject I am discussing. Given that the theoretical framework does not encompass the entirety of the task, I opted for a qualitative research approach. The interview subject is Martin Straume, chief engineer for P&A at Aker BP. One notable aspect of Aker BP's approach to P&A is its focus on minimizing operational impacts and costs. They employ advanced technologies and strategies that reduce the time required for abandonment operations, which is crucial in managing the financial and environmental costs associated with decommissioning old wells. Additionally, Aker BP's extensive experience in the North Sea, particularly in the Valhall field, provides them with unique insights into the complexities of P&A operations in challenging environments. This experience includes dealing with issues like subsidence and the integrity of well barriers, which are critical considerations for effective abandonment . Furthermore, Aker BP's strategic long-term planning in decommissioning and modernizing old platforms showcases their comprehensive approach to P&A. This includes the technical aspects of sealing wells and the broader logistical and environmental considerations involved in decommissioning large offshore installations. [23]

3.5.2. Analysis

Analysis involves thoroughly examining various components to elucidate a specific problem or development. To facilitate this, we developed a distinct interview guide before conducting our interviews. This guide was shared with the participants beforehand, and additional details about the topics to be discussed were communicated via email. This preparation ensured that the interviewees were well-informed and ready to engage fully in the discussions.

The interview proved invaluable, providing a diverse perspective rather than just theoretical insights from literature. This perspective will be integrated into my study's results section and contrasted with theoretical data in the discussion section. By comparing this practical insight with established theories, we can highlight the strengths and weaknesses of the theoretical framework. This approach will enrich the discussion on the research question and aid in drawing meaningful conclusions about my study.

3.5.3. Interview Transcription

For the interview I conducted via email, I adapted the transcription process to accommodate the textual format of the communication. I sent the interview questions to the participant via email, allowing ample time for them to consider and craft their responses thoroughly. Upon receiving their reply, I used the email responses directly to transcription the interview. This method effectively eliminated the potential for transcription errors commonly associated with audio recordings. To ensure the confidentiality and privacy of the interviewee, I carefully redacted any personal data and sensitive information from the transcription before proceeding with the analysis. The interviewee was informed about how their information would be used and consented to these terms before participating.

3.5.3.1. Follow-up

Following the interview, I emailed to pose follow-up questions and handle any subsequent issues. This approach to communication was well-received by both sides, as it allowed the interview object to reply at their own pace, ensuring thorough and thoughtful responses.

3.5.3.2. Analysis of Interviews

I posed questions related to my research topics during the interview, allowing the interview object to express themselves. They largely determined the duration of the interview. I used the mail exchanges as the transcript to avoid any unforeseen errors. This approach ensured that I captured all the valuable and detailed information during the interview.

3.6. Literature Studies

For my research on TTA, I extensively utilized studies and reports available through OnePetro, a comprehensive online resource managed by the Society of Petroleum Engineers (SPE). This platform gave me access to various technical papers and detailed analyses pertinent to my topic. I carefully selected the most relevant documents from OnePetro to ensure my study was based on the most up-to-date and authoritative information on well abandonment practices. The same could be said of Science Direct.

3.7. Sources of Error

In research, it is critical to reduce errors and identify sources of potential bias, a process that often requires detailed attention. Systematic biases are particularly problematic in research, as they can direct results in misleading ways, unlike random errors, which are directionless. In the context of interviews, a notable source of bias could arise if interviewees need to be more objective, particularly if their views conflict with the interests of their employers. To address this, various questions were formulated on the topic, and thorough comparisons were made between the responses from the interview and existing published documentation. This comparative analysis was conducted to verify the accuracy and justify the reliability of the information collected. Despite the inherent risk of bias in interviews, precautions were taken to validate the responses as dependable. Insights derived from this interview have substantially contributed to a deeper understanding of the subject matter, treating the gathered data with a critical eye for accuracy while acknowledging potential biases. [4]

4. Results

In this Results chapter, I will present the findings from the interviews and publications I discovered during my research. The interview will be retold through text to illustrate the point from the interview transcript.

4.1. Interview

The interview process started on 4 April 2024 and concluded on 10 May 2024. It was conducted via mail.

Martin Straume, Chief Engineer for Plug and Abandonment at Aker BP, explains that to fully realize the benefits of Through-Tubing Abandonment (TTA), specific technologies that are not yet available need to be developed. This includes logging technology capable of functioning through the tubing, A-annulus, and casing to verify the presence of an external casing barrier. This verification can only be omitted if an external casing barrier has been previously confirmed during well construction or recompletion. Currently, no through-tubing logging tools are approved by the Norwegian industry.

Tools that can log through 7.0” tubing are available but generally only applicable to gas wells in Norway. However, no operators on the Norwegian Continental Shelf have approved them for full verification use yet. For tubing sizes from 5 ½” and smaller, no approved logging tools are available in the industry, including most of Norway's oil wells.

Martin also highlights another critical requirement: the A-annulus must be filled with fluid. For these logging tools to function, all gas (from, for example, gas lift wells) must be removed. Gas significantly interferes with ultrasound signals, either stopping them outright or dampening them so that the readings cannot be relied upon.

TTA can only be conducted in Norway if it has been verified and documented that external casing barriers are already in place. There are differences from Norway to other countries. The Norwegian Petroleum Law, Havtil's regulations, and NORSOK D-010 are considered some of the strictest regulations in the world, and they apply to the entire Norwegian Continental Shelf.

Martin points out that once the technology is in place for TTA, the most significant advantage is that P&A can be performed more cheaply and in less time than today. This would postpone expensive rig operations, providing substantial financial benefits, especially relevant in Norway, where taxpayers cover 78% of P&A expenses. Another advantage is the ability to leave old tubing in the well, saving costs related to offshore handling, shipping to land, cleaning, and disposal of tubing, thus reducing economic and safety risks.

Despite its benefits, TTA presents operational challenges. Due to current technological limitations, Aker BP has only implemented TTA in the lower sections of wells. Logging through tubing and casing is hoped to be available in a few years, but currently, no tools can read through the tubing, and two casing layers are available. This means that if barriers outside the 13 3/8" casing shoe are not verified during well construction or recompletion, TTA cannot proceed from that depth upward, necessitating the removal of tubing to log for barriers.

As Martin notes, the main challenge is that it has yet to be verified whether well barriers are in place outside the casing during well construction and recompletion. If external barriers have yet to be verified, there is a lack of technology to log through tubing and casing today.

If the location of external casing barriers is known, perforating tubing and circulating cement in place in the A-annulus at the same depth as the external casing barrier is possible. A “Cross-sectional” barrier, as NORSOK requires, can be created by leaving cement inside the tubing. In such cases, an external control line attached to the tubing that goes down to a bottom hole gauge for pressure and temperature measurement cannot pass through a cement plug. The control line can then quickly become a leakage point.

Currently, only various types of cement are qualified as a barrier material that can be used deep in the well. Geopolymer or epoxy materials have yet to be approved. Bismuth is approved in Norway only at shallow depths. Recently, a methodology to qualify shale creep as a full-fledged barrier has been developed. Aker BP has been involved in establishing this in NORSOK D-010 as an option for operators.

Looking to the future, Martin believes that TTA could be much more widely used if there is consciousness of what needs to be verified during well construction. To use TTA, external barriers must be verified during well construction, or logging tools that can read through tubing and casing must be available. This often becomes a cost discussion.

Development of logging technology for tubing and casing (but only one casing string) is well underway. This means that all tubing must be pulled over the 13 3/8" casing shoe if it is unknown whether external barriers are in place (if needed). Logging tools can be run on the drill string when drilling the next hole section. Such a tool could be a way to verify external casing barriers on the “previous casing.” This would save an extra wireline logging run during well construction. However, it involves a more expensive BHA being run inside the well to drill the next hole section, and if there is bad luck in getting stuck and thus losing this logging tool, a significant economic risk is discussed.

4.2. Publications

The Publications section underscores pivotal works that have significantly shaped and expanded the scope of this thesis. It showcases a selection of case studies and research papers derived from real-life examples and notable discoveries. Each publication has been carefully selected to illuminate challenges, innovative solutions, detailed analyses, and critical discoveries pertinent to the study's topic. This compilation enriches the discussion and reinforces the research by demonstrating how theoretical insights are applied in practical scenarios, thus providing a robust foundation for addressing the questions at the heart of this thesis.

4.2.1. Case Study 1: Successful Customized Thru-Tubing Plug & Abandonment from a Light Well Intervention Vessel

In a case study on offshore well abandonment, a combined barrier approach was implemented using through tubing with coiled tubing (CT). This involved initial cement injection into the well annulus, then cementing the production tubing, using specialized CT tools for optimization. [10]

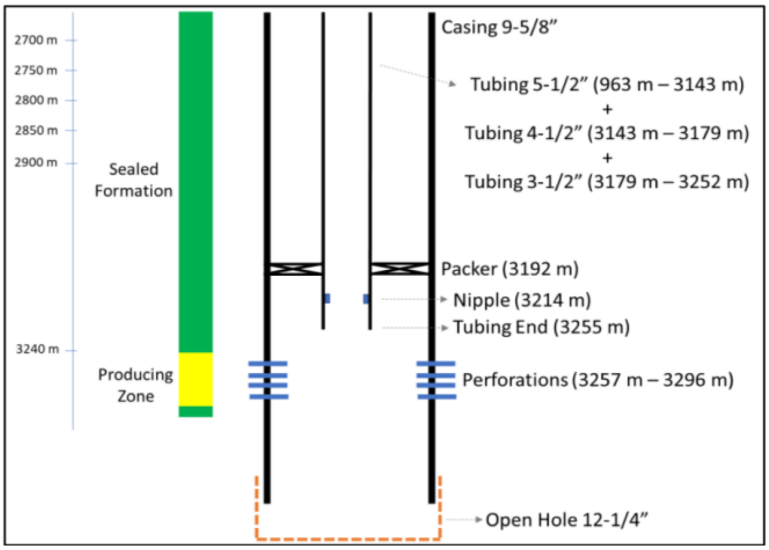

Figure 5 - Illustration of the well components and formation at the interested zone [10]

Operation Overview

Preparation:

Flushed the well and verified tubing depths.

Conducted CT intervention with drift and jetting to check packer integrity and clean the setting depth using a 1/8 inch OD bar with downhole sensors, completed in 30 minutes while monitoring temperatures and pressures.

Standing Valve Installation:

Installed and pressure-tested the standing valve (STV) at 3214 meters using a slickline.

CT with a bottom hole assembly-casing collar locator (BHA-CCL) was used to set the inflatable cement retainer (ICR) at 3159 meters, carefully monitoring pressures and temperatures.

Cementing Process:

Flushed the well again and pumped brine through the CT, ICR, and annulus for fluid circulation.

Pumped 30 barrels of washing fluid and 19.4 barrels of cement into the annulus, ensuring proper placement with 39.9 barrels of brine.

Conducted a cement evaluation logging run to verify cement integrity.

Cemented from 3147 meters to 3062 meters using CT positioned strategically.

Completion:

Positioned CT 10 meters above the theoretical Top of Cement (TOC) for cleaning operations.

Tagged TOC at 3073 meters after a 20-hour wait for the cement to set.

Concluded by cutting CT above the cement barrier at 3039 meters, extracting the subsea stack and tubing.

Conclusion

The plug and abandonment (P&A) operations were successfully executed, adhering to detailed methodologies. Strategic planning prevented common issues like cement misplacement and CT sticking. This novel thru-tubing technique led to significant operational efficiencies, achieving time savings of 30-40% and cost reductions of 50-60%, demonstrating the effectiveness of design and execution in offshore P&A operations.

4.2.2. Case Study 2: Cement Placement with Tubing Left in Hole during Plug and Abandonment Operations

P&A operations aim to restore cap rock functionality and permanently maintain well integrity. In Norway, the high costs of P&A operations can account for 40-60% of a field's total decommissioning costs. To reduce costs, leaving production tubing in the well is proposed, though concerns exist about cement displacement quality due to tubing centralization and flow dynamics in the annulus. [23]

Experimental Equipment and Methods

Full-scale tests were conducted with 7-inch tubings in 9 5/8-inch casings using conventional and expandable cement. The quality of cement placement was evaluated through pressure tests and visual inspections.

Test

Assembly #	Cement type	Control lines
Conv-A	Conventional	No
Conv-B	Conventional	Yes
Exp-A	Expandable	No
Exp-B	Expandable	Yes
Exp-C	Expandable	Yes

Figure 6 - Overview of different test assemblies [23]

Tests with Conventional Cement

Two assemblies, A and B, were used, each 36 meters long and inclined 85° off vertical. Conventional cement slurry displaced brine at a rate of 300 L/min. Pressure sensors measured internal pressures, and flow tests were conducted after curing for about a week.

Tests with Expandable Cement

Three assemblies, A, B, and C, each 12 meters long, were tested. Expandable cement was pumped at 300 L/min, displacing water. During curing, the assemblies were externally heated to 90°C. Pressure and flow tests were performed after three weeks, and flow measurements were conducted using water and light oil.

Results

Conventional Cement:

Flow tests indicated small, permanent micro annuli due to cement shrinkage during curing.

Visual inspection showed good cement placement, including around control lines.

Expandable Cement:

Provided better sealing than conventional cement.

Induced micro annuli were observed during pressure testing.

Visual inspection confirmed effective cement displacement.

Conclusions

The study demonstrates that effective cement placement is achievable with tubing left in the hole, reducing P&A costs and operational time. Expandable cement offers better sealing performance. The presence of control lines did not significantly impact leakage rates.

5. Discussion

This section will address the research questions that have steered my thesis based on data gathered from a single interview and a series of publications. Here, I aim to critically analyze the advantages and disadvantages of the theories and practices related to TTA compared to traditional plug and abandonment methods. This will be accomplished by discussing critical insights from the interview and findings from the publications.

As highlighted in my literature review, this part of my thesis will delve into well abandonment techniques' procedural and technological nuances. I will illuminate each method's strengths and weaknesses by integrating the interview and case study responses.

The objectives of my thesis are to explore and draw conclusions on several pertinent issues, including:

- How Through Tubing Abandonment Differs from Traditional Plug and Abandonment Methods
- The Most Common Challenges and Technical Barriers Encountered During TTA Operations
- What emerging technologies and innovations hold the potential to further enhance TTA practices?

The central question I seek to answer is the challenges and possibilities connected to TTA providing a safe and effective solution for abandoning oil and gas wells.

5.1. TTA vs P&A

Through Tubing Abandonment (TTA) and traditional plug-and-abandonment (P&A) are two distinct methodologies employed in the oil and gas industry to ensure that non-productive or end-of-life wells are safely and effectively decommissioned. Each method has unique procedures, technologies, and operational implications, making it suitable for different scenarios based on well architecture, environmental considerations, and regulatory requirements. Traditional P&A operations typically involve a comprehensive process where the well is accessed by removing the existing tubing, followed by setting cement plugs across the wellbore in multiple zones to isolate the hydrocarbon-bearing formations. This method requires extensive and often complex well interventions, including the complete retrieval of downhole equipment, which can be both time-consuming and costly. Removing equipment and tubing is necessary to provide clear access for placing cement plugs effectively, ensuring a secure and permanent seal. In contrast, TTA simplifies this process by utilizing the existing tubing within the well. This method allows operators to conduct abandonment operations directly through the production tubing, eliminating the need for its removal. Cement plugs or other sealing materials are deployed through the tubing to isolate the well zones, leveraging the tubing as a conduit. This approach reduces the duration and decreases the environmental impact associated with the heavy interventions typical in traditional P&A. As Martin Straume mentioned in the interview, further advanced logging tools need to be deployed to the through tubing operations to evaluate through the tubing, A-annulus, and the casing, which is currently not available in the Norwegian industry. However, this verification can only be avoided if an external casing barrier has been verified during well construction and recompletion. However, some tools can log through 7.0” tubing (such oversized tubing is generally only relevant for gas wells in Norway). Still, no operators on the Norwegian continental shelf have approved it for full verification use yet. For tubing sizes from 5 ½” and smaller, there are no approved logging tools in the industry yet. This applies to most oil wells in Norway. This means that from the 13 3/8" casing shoe and upwards in the well, we will NOT be able to log for barriers. This means that if they have not verified barriers outside the 13 3/8” casing during well construction or a recompletion, TTA cannot be used from that depth and upwards. They are thus forced to pull tubing from the 13 3/8" shoe and up to be able to log for barriers outside the 13 3/8" casing. Furthermore, he explains that the A-annulus needs to be entirely free of gasses for the operation to commence with logging through ultrasound signals. This highlights how TTA differs from traditional P&A with a necessity for further logging, verification, and development in logging technology.

The choice between TTA and traditional P&A often hinges on the condition and integrity of the well. Traditional P&A is necessary when the structural integrity of the tubing or the surrounding casing is compromised, which could prevent effective sealing through the tubing. In such cases, removing the tubing to access and evaluate the casing directly becomes essential for ensuring that the abandonment meets safety and environmental standards. Additionally, Martin Straume highlights that TTA abandonment can only be carried out in Norway if it has been verified and documented that an external casing barrier is already in place. However, when the integrity of the tubing and casing is intact, TTA offers a less invasive alternative that significantly reduces the risk of environmental contamination. By not requiring tubing removal, TTA minimizes the disturbance to the marine environment in offshore settings and reduces the potential for accidental spillage or leakage of reservoir fluids. TTA can often be performed using no or lighter intervention vessels, further reducing the operational footprint. This capability is particularly advantageous in offshore environments, where heavy rigs have a greater logistical and environmental impact. The ability to use smaller, more versatile vessels not only reduces costs but also allows for greater flexibility in scheduling and executing abandonment operations.

Economically, TTA is generally more cost effective than traditional P&A. The reduced need for heavy machinery, less rig time, and fewer on-site personnel contribute to lower operational costs. Additionally, the shorter duration of TTA compared to traditional P&A means that the costs associated with downtime, such as lost production opportunities, are also minimized. This makes TTA an attractive option for operators, especially in fields with multiple wells requiring abandonment, as it allows for more rapid project execution and the potential for significant cost savings. As discovered in case study 1, the ABEX results were impressive for the TTA operations, yielding 50 to 60% total cost reductions compared to the traditional plug and abandonment.

From a regulatory perspective, both methods must meet stringent industry standards and government regulations to ensure that abandoned wells do not pose a future environmental or public safety risk. However, the regulatory acceptance of TTA can be more complex due to the need to demonstrate that the existing tubing and the seals provided through this method are as robust and reliable as those achieved by traditional P&A. This is further confirmed by Martin Straume's comments, which mention that although there are differences from one country to another, Norwegian regulations are some of the strictest. This is especially true for TTA operations with newer risks and uncertainties compared to the traditional plug-and-abandon method. [1]

Safety is paramount in both approaches, but TTA can offer enhanced safety benefits by reducing the amount of heavy lifting and operations required to retrieve tubing and equipment from the well. This reduction in complex field operations minimizes the risk of accidents and injuries to personnel and the potential for mechanical failures that could lead to environmental incidents. This is demonstrated in case study 1, as it was noted that the time saved on the TTA operation was between 30 and 40%. This is further expressed through Martin Straume, mentioning that when the necessary technology is in place for TTA, the most significant advantage will be that they can carry out P&A more cheaply and in less time than today. They will be able to delay the use of expensive rigs. This will mean the most significant reductions for the Norwegian state, as the taxpayers cover 78% of the expenses for P&A.

5.2. Challenges

One of the primary technical challenges in TTA is achieving proper cement placement, which is critical for creating a reliable seal to prevent fluid migration. Specific issues like the eccentricity of tubing within the casing complicate cement placement. The tubing is only sometimes centralized, leading to uneven cement distribution. Equipment like gauge cables or control lines within the annulus further complicates the cementing process, as these can create pathways for fluid migration if not correctly sealed. Techniques such as expanding cement or vibration tools are implemented to enhance cement placement. [22]

However, these methods require precise execution and verification to ensure the integrity of the cement sheath. Case study 2 conducted a test on cementing with regular and expandable cement with control lines on the tubing. They concluded that in the performed tests, seepages were observed within the assemblies; however, the flow rates were notably low, and the micro-annuli were small and varied. These characteristics indicate that such seepages are unlikely to result in major leaks or pose significant issues in practical applications, especially in wells with extensive cemented annulus. Significantly, incorporating control lines into the assemblies did not substantially increase seepage rates, implying that control lines do not critically undermine the sealing process when appropriately incorporated. Such studies were integral in changing regulations regarding the control lines. In NORSOK D-010, it is mentioned that control lines and continuous cables are typically not part of the permanent well barriers. However, they may be considered part of these barriers if effective isolation within these lines is secured. [1]

Evaluating and sealing potential leakage pathways and examining the wear and tear on the cables or control lines' materials is necessary to secure well integrity. And, as Martin Straume noted, If they know where the external casing barriers are, one can perforate the tubing and circulate cement in place in the A-annulus at the same depth as the external casing barrier. Leaving cement inside the tubing will create a Cross-sectional barrier, as the NORSOK D-010 requires. In such cases, one cannot have an external control line attached to the tubing that goes down to a bottomhole gauge for pressure and temperature measurement. If present, such a continuous control line cannot pass through a cement plug. The control line could then quickly become a leakage point.

Ensuring the integrity of existing well structures is another hurdle. Corrosion, scale build-up, or mechanical damages can adversely affect the tubing and casing, complicating the abandonment process. These integrity issues can lead to unreliable cement seals and necessitate additional interventions like tubing removal or extensive cleaning, adding complexity and cost to the abandonment operations. [21]

Challenges might occur with the logistics of using Lightweight Intervention Vessels (LWIV). These vessels offer a lighter, more cost-effective solution for abandonment operations but come with equipment capacity and operational space limitations. Additionally, operational challenges include managing the presence of internal well components like gas lift valves, which can interfere with fluid displacement during cementing. These factors require strategies to mitigate risk and ensure a robust abandonment process. [19]

Verifying the integrity of cement barriers is a significant technical barrier. In operations with tubing in place, acoustic and ultrasonic logging have merits and limitations. Acoustic logging offers robustness and penetration depth, suitable for a broader well integrity evaluation. In contrast, ultrasonic logging excels in high-resolution imaging and detailed assessment but faces challenges related to signal attenuation and complexity in data handling. The choice between these methods often depends on the specific conditions of the well, the level of detail required in the cement evaluation, and the technical capabilities of the operating team. Alternative verification methods, such as pressure testing or tracer dyes, are discussed, providing additional means to ensure the effectiveness of the cement barriers. This is what Martin Straume highlighted throughout the interview. To fully benefit from performing through-tubing abandonment, there is a need for technologies not available today. This includes logging technology through tubing, the A-annulus, and casing to verify that an external casing barrier is in place. [16]

5.3. Possibilities

One of the most promising areas of innovation is developing new sealing materials designed explicitly for TTA applications. Traditional cement has been the go-to material for well plugging due to its durability and cost-effectiveness. However, new polymer-based compounds are being developed to expand upon the setting, filling the irregularities and gaps within the wellbore more effectively than conventional materials. These intelligent materials are designed to react to downhole conditions, such as temperature and pressure changes, to form a tighter, more resilient seal. Additionally, more environmentally friendly bio-based sealants are being tested for their effectiveness in sealing applications, offering the potential to reduce the environmental impact of well abandonment. Martin Straume mentioned that various types of cement are currently the only barrier materials qualified for use deep within wells. Materials such as geopolymers or epoxies have yet to be approved. In Norway, the use of bismuth as a barrier material is only authorized at shallow depths. Additionally, recent advancements have led to methodologies for qualifying shale creep as a fully effective barrier. Aker BP has been instrumental in integrating this methodology into the NORSOK D-010 standard, providing operators with this additional option for well integrity management. [18]

Robotics technology also holds significant potential to transform TTA practices. Robots equipped with advanced sensors and manipulation tools can perform complex tasks inside the tubing, such as deploying plugs, conducting inspections, and even carrying out minor repairs or removing obstructions without the need to remove the tubing. This capability could drastically reduce on-site workforce and equipment, minimizing human exposure to hazardous conditions and reducing the overall carbon footprint of abandonment operations. [17]

Acoustic and ultrasonic imaging technologies are undergoing rapid advancements, with new tools capable of providing higher-resolution images and more precise measurements of cement integrity through tubing. These tools use higher-frequency sound waves to detect finer details and minor defects within the cement sheath. Enhancements in signal processing algorithms and sensor technology allow these tools to overcome the challenges posed by the tubing and casing, offering a clearer picture of the cement's condition and the effectiveness of the abandonment, as Martin Straume revealed in the interview. Aker BP is currently making strides in developing logging technologies for tubing and casing, although it's currently limited to a single casing string. If there is uncertainty regarding external barriers, all tubing might need to be pulled out over the 13 3/8" casing shoe. However, new logging tools that can be run on the drill string while drilling the next section of the hole are now available. These tools allow for verifying external casing barriers on the "previous casing," which could eliminate the need for an extra wireline logging run during well construction. Utilizing these tools involves higher costs for the bottom hole assembly (BHA) used in drilling and poses a significant financial risk if the tool gets stuck and is lost in the well. A recent advancement in the oil and gas sector is the evaluation techniques of the Through-Tubing Casing Evaluation (TTCE) tool. This innovative tool utilizes electromechanical impedance and selective non-harmonic resonance principles to assess the bond between casing and cement in a wellbore, all without the need to remove tubing. Furthermore, enhancements in data analytics and software development can be implemented to refine data processing, including eccentricity correction and data interpretation, ensuring a comprehensive evaluation of cement integrity. The effectiveness of this technology has been demonstrated through simulations and laboratory experiments, indicating its potential value. However, further validation through laboratory tests and field trials is planned to evaluate its performance under higher tubing eccentricity and tubing decentralization with varying tubing and casing dimensions. Ongoing research aims to enhance the forward modeling module to address non-harmonic responses in pipe deformation or ovality scenarios. Despite these ongoing developments, the TTCE tool represents a significant advancement in well integrity evaluation, offering improved operational efficiency, sustainability, and safety by eliminating the need for tubing removal. This technological innovation holds promise for enhancing well evaluation practices in the oil and gas industry. [16]

Data analytics and machine learning are becoming increasingly integral to TTA operations. The vast amounts of data generated during drilling, production, and abandonment can be leveraged to gain insights into the most effective techniques for well abandonment. Predictive models can be developed to assess the likelihood of well integrity issues before they become problematic, allowing for proactive management of well abandonment. This approach improves the efficiency and effectiveness of TTA practices and helps extend the life of existing wells by predicting and mitigating potential failures. A recent example showcasing this is a recent introduction of a machine learning workflow to enhance Through-Tubing Cement Evaluation (TTCE), specifically by addressing the impact of tubing eccentricity on cement bond measurements. Using a feedforward neural network trained with forward modeling data, the algorithm effectively correlates patterns in the data with casing-to-cement bond indices, minimizing tubing decentralization effects. Results show that the ECC correction algorithm accurately estimates bond indices within desired error margins, as validated by lab experiments. Further tests are needed to evaluate its performance under various conditions. Despite some limitations, this algorithm significantly improves TTCE, enhancing measurement accuracy and operational efficiency. [15]

TTA tools are essential in the oil and gas industry, especially when decommissioning outdated or non-productive wells. The primary function of these tools is to ensure that such wells are sealed effectively to prevent potential environmental contamination and hazards. This process is a regulatory requirement and a critical step in maintaining ecological integrity and public safety. TTA tools are designed to handle the complex tasks of abandoning a well below the surface without removing the well's tubing. This approach is favored for its efficiency and minimal environmental disruption. The tools used in TTA vary in function and design but generally include devices for placing and securing mechanical barriers like plugs and for delivering and setting sealing materials such as specialized cement within the well. An example of advancement is showcased in the results from a System Integration Test (SIT), which demonstrated an exponential improvement of the new tubing puncher gun. The average hole size increased by 60%, resulting in a 156% higher Absolute Open Flow (AOF) than the traditional tubing puncher. These findings were confirmed during the through-tubing Plug and Abandonment (P&A) campaign in Brazil, which included 20 operations so far. The cementing operation parameters consistently confirmed the superior performance of the new device. All cementing operations with the new system showed similar results, with no signs of circulation issues or other problems during cement slurry displacement. [11]

Integrating augmented reality (AR) and virtual reality (VR) technologies in TTA practices can enhance the training and execution of complex abandonment procedures. Using AR and VR, technicians can simulate various abandonment scenarios and visualize the internal components of the well in real time, allowing for better planning and execution of abandonment operations. This technology not only improves the safety and efficiency of operations but also helps bridge the skills gap in the industry by providing immersive, hands-on training experiences. [12]

Sustainability is becoming a key focus in developing new technologies for TTA. Innovations that reduce the environmental impact of drilling and abandonment operations are particularly valued. For instance, technologies that minimize the use of water and chemicals in the abandonment process or enhance the recyclability of materials used in well construction and abandonment are gaining traction. Another example could be Intelligent Power Management by Schlumberger. Intelligent power management is an advanced system that proactively reduces emissions, fuel consumption, and engine run time on the rig. This system combines automated software, an energy storage system, and the use of hydrogen to achieve these reductions. [20]

One oversight regarding the possibilities for further technological development is competition oversight. In the highly specialized field of TTA in the oil and gas industry, competition is a significant driver of technological innovation. Companies in this sector are perpetually pushing the boundaries of technology to develop more efficient, cost-effective, and environmentally sustainable methods of well abandonment. This competitive environment fosters rapid technological advancements such as robotics, acoustic imaging, and new sealing materials. Each firm strives to offer superior solutions that promise to streamline operations and ensure compliance with stringent environmental regulations and safety standards. However, focusing on outcompeting rivals can also lead to fragmented efforts where similar technologies are developed in parallel without substantial improvements. This can result in a dispersion of resources and potential duplication of research efforts, which might slow the pace of significant technological breakthroughs. Contrasting with the competitive model, collaborative efforts in TTA can yield even more impactful innovations. When companies within the oil and gas industry join forces, they can combine their unique expertise, resources, and technological insights, leading to the development of breakthrough technologies that might be unachievable independently. For example, joint ventures or industry consortia can address complex challenges like deep-sea plugging, where single entities' cost and technical demands can be prohibitive. Through collaboration, these partnerships can leverage shared technologies to achieve more effective results, driving the entire industry towards safer, more efficient, and sustainable abandonment practices. An example of an alliance is the Well Intervention and Stimulation Alliance. This alliance is between Aker BP, Schlumberger, and Stimwell Services. This alliance focuses on accelerating and boosting oil production through innovations and digitization. While competition undoubtedly spurs companies to innovate continuously, collaboration can often catalyze more profound, more transformative technological progress, leading to advancements reshaping the landscape of tubing abandonment technology. [13], [14]

6. Conclusion

This section will address each thesis research question through a conclusion.

How Through Tubing Abandonment Differs from Traditional Plug and Abandonment Methods

Through Tubing Abandonment (TTA) and traditional Plug and Abandonment (P&A) represent two critical methodologies in decommissioning oil and gas wells. Each method has distinct advantages and challenges, making them suitable for different scenarios based on well conditions, regulatory requirements, and environmental considerations. Traditional P&A, while comprehensive and reliable, involves extensive well interventions and the complete removal of downhole equipment, resulting in higher costs and longer operational times. On the other hand, TTA offers a less invasive alternative by utilizing the existing tubing, significantly reducing operational time, environmental impact, and costs.

The choice between these methods often depends on the structural integrity of the well and the presence of verified external casing barriers. TTA is particularly advantageous in offshore environments where minimizing environmental disturbance and operational footprint is crucial. However, its application is limited by current technological constraints in logging and verification tools, as highlighted by Martin Straume's insights into the Norwegian industry. Ensuring the integrity of seals and compliance with stringent regulatory standards remains a challenge for TTA, necessitating further advancements in logging technologies.

Economically, TTA's potential for cost savings and shorter project durations makes it an attractive option for operators, especially in fields with multiple wells requiring abandonment. Safety benefits are also significant, as TTA reduces the complexity of field operations, thereby minimizing risks to personnel and the environment. Ultimately, the ongoing development and refinement of TTA technologies and methodologies will enhance its viability and regulatory acceptance, offering a promising future for more efficient and environmentally friendly well abandonment practices.

The Most Common Challenges and Technical Barriers Encountered During TTA Operations

Through Tubing Abandonment (TTA) faces several technical challenges, particularly in achieving proper cement placement and ensuring well integrity. The eccentricity of tubing, the presence of gauge cables or control lines, and the integrity of existing well structures such as tubing and casing complicate the cementing process. While beneficial, Techniques like expanding cement or vibration tools require precise execution and verification. Studies, such as Case Study 2, indicate that seepages can occur but are typically minor and manageable, provided control lines are appropriately integrated.

The logistical limitations of Lightweight Intervention Vessels (LWIV) and the presence of internal well components further complicate abandonment operations, necessitating specific strategies to mitigate risks. Ensuring the integrity of cement barriers is critical, with acoustic and ultrasonic logging providing essential but imperfect solutions. These methods and alternative verification techniques like pressure testing or tracer dyes offer means to validate cement seals, though their effectiveness varies based on well conditions and technical capabilities.

Despite these challenges, TTA presents a viable and less invasive alternative to traditional plug-and-abandonment (P&A) when well integrity is maintained and proper verification is possible. The ongoing development of advanced logging technologies and improved cementing techniques will be crucial for enhancing the efficacy and reliability of TTA. As highlighted by industry insights, particularly from Martin Straume, the need for new technologies to verify external casing barriers and ensure comprehensive well integrity remains a significant area for future innovation. Addressing these technical challenges will enable more efficient, cost-effective, and environmentally friendly well-abandonment practices.

What emerging technologies and innovations hold the potential to further enhance TTA practices?

Developing new sealing materials, robotics, and advanced imaging technologies presents significant potential for improving Through Tubing Abandonment (TTA) practices in the oil and gas industry. Innovations in polymer-based and bio-based sealants promise better adaptability to downhole conditions, enhancing well abandonment operations' effectiveness and environmental sustainability. Despite the current limitations, particularly in approving and using specific materials and technologies, advancements are being made. For instance, incorporating shale creep as an effective barrier and enhancing logging technologies are already shaping future standards and practices.

Robotics technology offers transformative potential by enabling complex tasks within the tubing, reducing the need for extensive human intervention and heavy machinery, thereby lowering operational costs and environmental impact. Similarly, acoustic and ultrasonic imaging technology advancements provide higher-resolution data, which is crucial for verifying cement integrity and ensuring robust abandonment processes. Tools like the Through-Tubing Casing Evaluation (TTCE) and machine learning algorithms further enhance the accuracy and efficiency of these evaluations.

Data analytics and machine learning are becoming increasingly integral to TTA operations. They offer predictive models that enhance decision-making and operational efficiency. By leveraging historical and real-time data, these technologies enable proactive, good integrity management, reducing the risk of failures and extending the operational life of wells.

Moreover, sustainability is a growing focus, with innovations aimed at reducing the environmental impact of TTA operations. This includes developing eco-friendly materials and intelligent power management systems that reduce emissions and fuel consumption.

Competition and collaboration within the industry both drive technological innovation. While competition fosters rapid advancements and efficiency, collaboration can lead to more significant breakthroughs by combining resources and expertise. Alliances such as the Well Intervention and Stimulation Alliance exemplify how joint efforts can accelerate technological progress, offering safer, more efficient, and sustainable well abandonment solutions.

Overall, integrating these emerging technologies and collaborative approaches holds great promise for advancing TTA practices, ensuring well integrity, and minimizing the environmental footprint of well abandonment operations.

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