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Alternatives to conventional rig for P&A on fixed installations

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Abstract

Looking forward, there will be a need of performing a considerable number of permanent plugging and abandoning (PP&A) of oil and gas wells on the Norwegian Continental Shelf (NCS). These wells just cannot be left behind. The permanent plugging needs to be done either with or without a conventional rig tower. This thesis will cover the different surface equipment that can do plug and abandon (P&A) operations and the different downhole equipment that can aid in doing P&A operations without a conventional rig tower.

In 2015, a roadmap was made showing how one thought the development in rigless technologies would be [27]. One thought that within three years, the new development in rigless technologies would allow for P&A operations from start to finish, but even still today P&A operations are not done completely rigless. One can say that the development in this area has not been exactly how one anticipated.

By investigating different rigless technologies and their applications, this thesis aims to contribute valuable insights into the ongoing development within the oil and gas industry. As operators seek more sustainable and cost-effective solutions, the exploration of innovative rigless technologies emerges as key factor in the future of well abandonment on the NCS.

Today, the technologies for doing P&A without a conventional rig tower exists but not all the technologies are being used on the NCS due to health, safety and environment (HSE) regulations.

If the hydraulic workover units (HWO) make their pipe handling systems completely automated, and a red zone with no personnel activity while the equipment is in use, they will be allowed on the NCS.

If the more advanced HWO's are introduced, large parts of the P&A jobs can be performed without the use of conventional rig tower. It should also be noticed that improvements in downhole technologies will facilitate more use of rigless surface technologies.

The surface technologies this thesis will cover combined with new development in downhole equipment make it possible to P&A from start to finish.

Acknowledgements

This thesis has been a journey from start to finish with a big learning curve. I have met many different and interesting people and got to know the industry better. I would like to thank my supervisor at the University, Kjell Kåre Fjelde, for guiding and assisting me throughout this thesis. He has been helpful, and I appreciate it. I would also like to thank all the persons and companies for giving me good information and valuable input throughout this thesis.

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List of Abbreviations

P&A	Plug & Abandon
PP&A	Permanent Plug & Abandonment
NCS	Norwegian Continental Shelf
HSE	Health, safety and environment
HWO	Hydraulic Work Over
JSA	Job, safety analysis
XMT	Christmas tree
BOP	Blow Out Preventer
BHA	Bottom Hole Assembly
ID	Inner Diameter
OD	Outer Diameter
HC	Hydrocarbons
PWC	Perforate, Wash and Cement
RCT	Radial Cutting Torch
SJI	Slot Jet Isolate
WBE	Well Barrier Envelope

Introduction

Background

Norway have produced oil since 1972 and we are now entering a period where old wells have stopped producing oil and need to be PP&A. There are over 3000 wells on the Norwegian continental shelf (NCS) [3]. To do this the “old way”, is very expensive and time consuming. The market is screaming for technology that can cut cost.

For subsea wells, companies usually need to rent a semisubmersible rig to do the PP&A work. But for wells on fixed installations, they'd should rather use the rig tower for drilling new wells instead of plugging the old ones. Sometimes, there isn't a rig tower at all, and they have to hire a jackup rig for the job.

There's a need for new technologies that can replace the traditional rig tower on fixed structures or the expensive semisubmersible needed for underwater wells, either for the whole PP&A operation or just parts of it. This is called rigless PP&A technologies. Other concepts are the use of modular rig.

Purpose Of Thesis

In this thesis, the main objective is to describe technologies that can reduce or leave out the use of the conventional rig tower for PP&A.

Both surface and downhole equipment that can aid and simplify the P&A operations will be described.

General about P&A

When an oil well reaches the end of its useful life, we must make sure it doesn't cause harm to the environment by leaking any oil or gas. To do this safely, we perform something called "plug and abandonment" or P&A.

P&A is the process of making the well secure and preventing any harmful substances from escaping. This can be quite expensive. In some cases, it can even cost as much as the original drilling. So, it's important to find cost-effective ways to do this while still making sure it works well.

There are various reasons why a well's life might come to an end. It could be because the well is suffering from integrity issues, there's not enough oil or gas left, it's causing environmental problems, it's not financially viable, or we've gathered all the data we need for exploration. In such cases, we must permanently close and secure the well.

We can't just leave these wells as they are because it could be dangerous for safety and for the environment. That's why we need to create barriers to stop any hazardous materials from leaking into the surroundings. The main goal of P&A is to make sure the well stays sealed for good. To do this, we place barriers deep in the ground using the right equipment, following local rules set by the government.

These barriers are essential to protect the environment, fresh water sources, and nearby areas from any oil or gas that might try to escape. This usually happens through porous rock, which could be filled with water or HC. While the details of a P&A operation may vary a bit, depending on whether the well is being temporarily or permanent abandoned, the main aim is always the same: keep everything safely sealed up to prevent leaks [4].

Figure 1 shows before and after permanent abandonment of a wellbore with two permeable sources.

- Blue represents primary well barrier.
- Red represents secondary well barrier.
- Green represents open hole to surface plug.

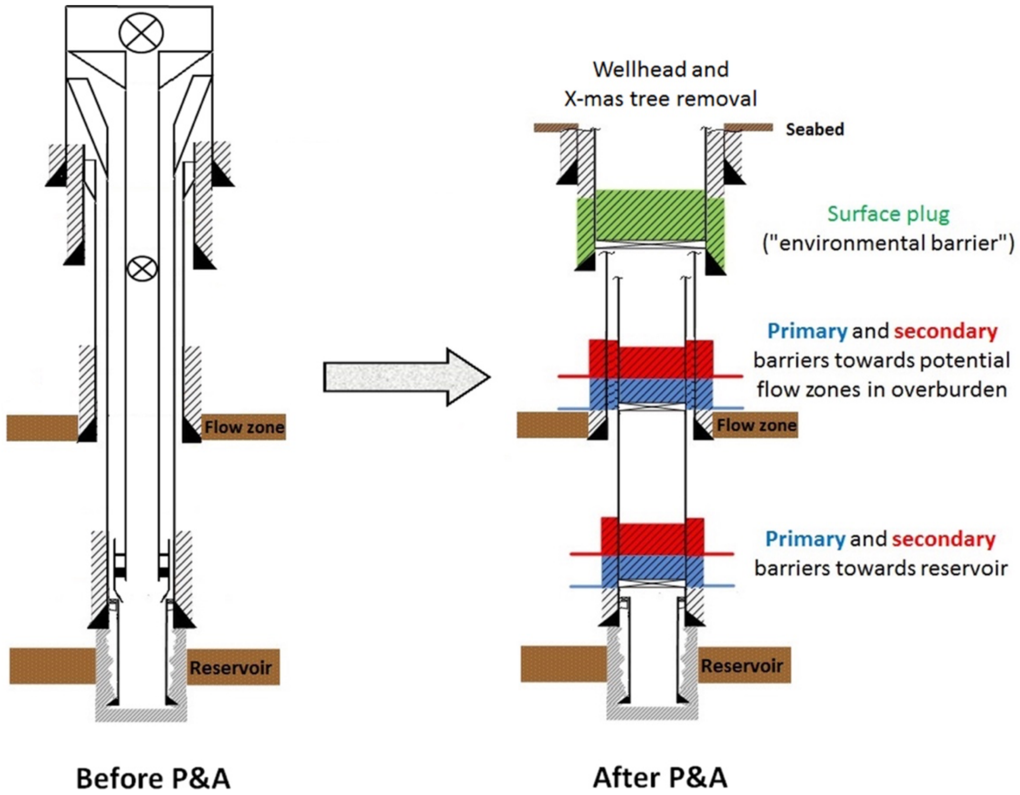

Figure 1 – Visual presentation of before and after P&A [5]

More about barriers will be in section “Barrier Requirements & Verification”.

General Requirements

Within every wellbore operation it is important to get in-depth knowledge of the current regulations and requirements. Every operator on the NCS is responsible for the safety of its own operation. On the NCS it is the latest version of NORSOK D-010 that sets the minimum industry standard in well integrity. NORSOK states "This document defines the minimum functional and performance requirements for well barriers through the life cycle of a well" [1].

NORSOK defines both requirements and guidelines. It is important to know the difference between these. NORSOK use the term *shall* to indicate requirements that needs to be strictly followed. *Should* is used when a recommendation is provided.

Each operator can set its own stricter requirements if they want. The rules states that when a well is no longer in use, or it does not have any plans of being used in the future, it must be permanently plugged within a reasonable time to protect it against future leaks [17].

If the well is not being used, but it will be in the future, the well can be temporary plugged for reentering in the future.

As of 1 January 2014 there came new requirements regarding temporary plugged wells on the NCS[6].

- *Where subsea-completed well are concerned, their integrity must be monitored if the plan is to abandon them for more than 12 months.*
- *Exploration wells must not be temporarily abandoned for more than two years.*
- *In production wells, hydrocarbon-bearing zones must be plugged and abandoned permanently within three years unless they are continuously monitored*.

The regulatory framework governing P&A requirements is outlined in the Petroleum Act, which succinctly mandates that a well must be entirely free of any potential sources of leakage when it is abandoned (Petroleum Safety Authority Norway, 2021). As stated in NORSOK-D010 it says, "*The general principle is to operate with two defined well barrier envelopes against over-pressure and/or flow potential zones*". In the event of any leakage occurring from the well after abandonment, the P&A operation will not receive approval from the Petroleum Safety Authority in Norway.

The abandonment section in NORSOK D-010 covers these scenarios [1]:

- suspension of well activities and operations;
- temporary abandonment of wells;
- permanent abandonment of wells;
- permanent abandonment of a section in a well (sidetracking, slot recovery) to construct a new wellbore with a new geological well target.

This thesis will mainly look at the requirements and verifications for permanent abandonment.

Barrier Requirements & Verification

The definition of a barrier is any fluid, plug or seal that prevents oil, gas or any other fluid from flowing unintentionally from a well or from a formation to another formation [11].

NORSOK D-010 does not state what materials the barrier is made of. It states the following properties [1]:

- Long term integrity
- Impermeability
- No shrinking
- Withstand mechanical loads
- Chemical stability – resistant to H_2S, CO_2, H_2O, brine and HC
- Shall bond properly to tubulars
- Shall not detrimentally affect properties of tubulars in contact with barrier material

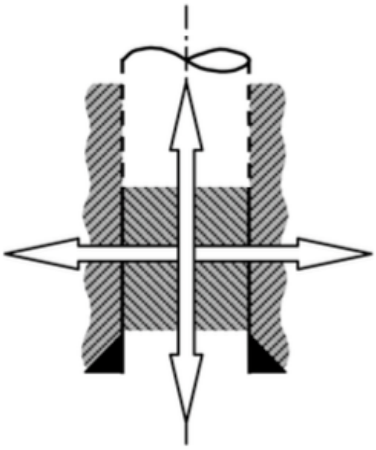

Figure 2 – Horizontal and vertical seal directions [1]

"*Permanent well barriers shall extend across the full cross section of the well, include all annuli and seal both vertically and horizontally*" *[1]* as shown in figure 2.

Minimum number of well barriers is two, primary and secondary. There are some exceptions shown in figure 3. The overall number of barriers depends on how many flow zones there is in the wellbore.

NORSOK D-010 states that multiple reservoir zones/perforations within the same pressure regime may be regarded as one reservoir for which a primary and secondary well barrier shall be installed [1].

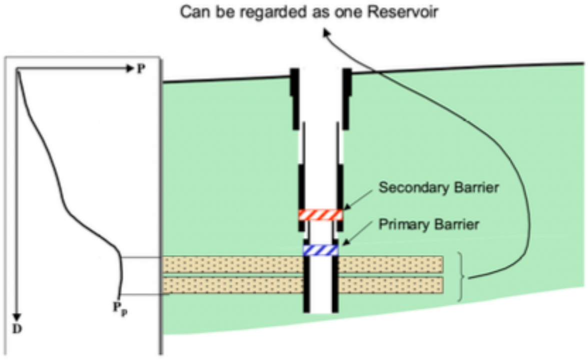

Figure 3 – Multiple reservoars [1]

One of the most used barriers is cement. Often combined with mechanical plugs. The minimum cement plug length shall be at least 50m MD if set on mechanical/cement plug as fundament. If not, the minimum length is 100m MD. The requirement in the annulus of well barrier is 2x 30m MD cement.

A well barrier envelope (WBE) consists of different well barrier elements.

NORSOK D-010 requirement for a qualified WBE is [1]:

- *Above a source of inflow/reservoir.*
- *Shall be adjacent to a hydraulically sealing formation with formation integrity exceeding the maximum expected pressure at the base of each interval.*
- *50 m MD verified by displacement calculations or 30 m MD when verified by bond logs.*
- *2 x 30 m MD verified by bond logs when the same annulus cement will be a part of the primary and secondary well barrier.*
- *For wells with injection pressure exceeding the formation integrity at the cap rock: The cement length shall extend from the upper most injection point to 30 m MD above top reservoir verified by bond logs.*
- *For the shoe track to be used as a WBE, the following applies:*
    - *The bleed back volume from placement of casing cement shall not significantly exceed the calculated volume; and*
    - *it shall be either pressure tested and supported by overbalanced fluid (see EAC 1) or inflow tested.*

After every cement plug is set, it needs to be tagged and pressure tested to be verified as a functional barrier [1].

Pore-pressure	Source of inflow	Minimum number of well barrier envelopes		
		Drilling, Completion & P&A Phase	**Production[9] / Injection/ Disposal Operations**	**After Permanent P&A**
Normal pressure Note that local over-pressured shallow hazards may occur in this interval	a) Interval with no hydrocarbon and no flow potential	One[1,2]	Not relevant[3]	Not relevant[4]
	b) Interval with hydrocarbon and flow potential (included depleted reservoir)	Two[2]	Two	Two[5]
	c) Shallow water flow potential	Two[2,6]	Two[6]	One
Over pressure	d) Interval with no flow potential (with or without HC)	Two	One[7]	One[8]
	e) Interval with limited flow potential (with or without HC)	Two	Two[8]	Two[8]
	f) Interval with flow potential (including reservoir)	Two	Two	Two

NOTE 1 This interval may be drilled with seawater providing a risk evaluation finds this acceptable

NOTE 2 A pilot hole is considered an acceptable method of de-risking potential shallow hazards, see 6.7.2.2.

NOTE 3 Surface casing should be cemented to surface during construction

NOTE 4 An open hole to surface plug is required

NOTE 5 A pilot hole with confirmed shallow gas should be cemented back to surface

NOTE 6 One barrier may be acceptable based upon a specific risk evaluation considering well/template/installation stability

NOTE 7 Casing and seal assembly. A specific risk evaluation of sustained casing pressure shall be performed, and mitigations incorporated in the well design or operating guidelines

NOTE 8 For overburden formations, with limited or no flow potential, the required number of barriers may be reduced by one providing a risk assessment demonstrates an acceptable risk level. The risk assessment shall cover all plausible load scenarios (including sustained casing pressure) and account for operational limitations and uncertainties in fluid type, pore-pressure, barrier conditions, etc.

NOTE 9 Gas-lift gas require two barrier envelopes

Figure 4 – Full list of minimum requirements for barriers with exceptions directly from NORSOK [1]

What Operations are Typical for P&A

Logging

Determine the status of the well. The first operation is to do a caliper run (measuring ID) to get a clear view on possible restrictions in tubing and log temperature and pressure.

Logging will also be used for logging annulus cement but it may be necessary to pull tubing first, depending on where the barriers are intended to be.

Kill well

This can be done by bullheading. This means pumping heavy fluid to push potential HC out in the formation. This operation is crucial since the Christmas tree (XMT) needs to be replaced with a blowout preventer (BOP) to carry on with the P&A operation.

Set temporary plug

When removing the XMT, a barrier is removed from the well. To sustain the well integrity, a temporary plug is required.

Nipple down XMT

To access the well with bigger equipment and sustain well integrity, it is required to have a BOP. Nipple down means to disassembly the XMT from the wellhead.

Nipple up BOP

Install a BOP on top of the wellhead to ensure well integrity during well operations.

Pull Production tubing

This is often needed to be able to check cement behind $9^{5/8}$ inch casing to set a cement barrier that seals both vertically and horizontally.

Cementing

If cement behind casing/liner is acceptable, a cement plug can be set against the permeable zone.

Milling or Perforate, wash and cement (PWC)

If cement in annulus does not meet the requirements, cut and pull casing, milling or PWC is different approaches to reinstate the annulus well barrier.

Cut and pull casing

At some stage the $9^{5/8}$ inch and $13^{3/8}$ inch casing needs to be cut and retrieved. The specific depth where it will be cut depends on the P&A design. At least, they must be cut deeper then where the environmental plug is to be placed. In some cases, it needs to be cut deeper due to several zones that have to be plugged.

Cut and retrieve conductor

For subsea wells, the wellhead will be cut a few meters below the seabed to avoid future obstacles at the seabed for other activities e.g. fishing.

Complexity Of P&A Operation

In some simple cases the tubing can be left in the hole if there is good cement in the annulus and there is no control lines attached to tubing. The latter can unfortunately create leakage paths if not removed.

If a log shows bad cement in annulus, there are three different approaches.

- Cut and pull casing
- Section milling
- PWC

Cut and pull casing can be a difficult and time-consuming operation to do. If there is settled barite behind the casing, it can be really stuck. If this is the case, then the casing gets cut in to smaller and smaller pieces until the rig can pull it out. This operation puts a great strain on topside equipment. If the jar is used, then this will result in extra and more detailed inspection of the derrick after usage. All this combined leads to more time used.

A downhole jacking tool can make this operation easier and will be described in the section "Downhole Equipment For Aiding P&A-Operations" later in this thesis.

Section milling is an option to cut and pull casing where a specific interval of casing is being milled to access the specific area where the barrier needs to be set. The downside of this method is the steel cuttings (swarf). Handling swarf at surface is a HSE risk for personal and requires certain specifications of surface equipment. Cleaning the hole and BOP is time consuming and can be problematic [25]. Milling requires rotation of milling bit, usually done by rotating the drill string. If using a mud motor, milling operations can be done by coiled tubing.

PWC is a cost effective and efficient alternative to section milling when annulus cement does not meet the requirements. It is efficient because only one run is needed to set a new functional barrier behind the casing.

PWC consists of a downhole workstring with a perforating gun filled with explosives to perforate the casing, a cup wash tool with jet nozzles to clean out debris behind the casing. Finally, a cement stinger and a twisted rubber bladed to squeeze the cement behind the casing [34].

UK Classification of P&A

There are three phases of P&A according to Offshore Energies UK [24]. They are described below. But there is a lot of operations that needs to be done before we can start on phase 1. So therefore "Phase 0" was suggested added in [16]. To be clear, there is no official phase 0, but it is good to include in the classifications because these operations needs to be done. So therefore we can get a better view of what needs to be done to P&A a wellbore from start to finish.

Phase 0 – Preparatory work

- pre-P&A work such as killing the well, logging and installing deep set mechanical plugs.

Phase 1 – Reservoir abandonment

- Primary and secondary permanent barriers set to isolate all reservoir producing or injection zones. The tubing may be left in place, partly or fully retrieved. Complete when the reservoir is fully isolated from the wellbore.

Phase 2 – Intermediate Abandonment

- Includes: Isolating liners, milling and retrieving casing, and setting barriers to intermediate hydrocarbon or water bearing zones an potentially installing near-surface cement. The tubing may be partly retrieved, if not done in Phase 1. Complete when no further plugging is required.

Phase 3 – Wellhead and conductor removal

- Includes: Retrieval of wellhead, conductor, shallow cuts of casing string, and cement filling of craters. Complete when no further operations are required.

P&A Program from Valhall DP

The Valhall field have many permeable zones. The following shows an example of the activities involved when plugging the different zones [20].

P&A phase 1

- well clean-out with inhibited seawater
- install plug @2782,6mMD
- displace well with brine
- Set inflatable plug in 5 inch liner
- Set cement plug in 5 inch liner
    - All the above executed with coiled tubing
- Cut tubing
    - Executed with wireline
- Displace A-annulus and tubing to inhibited seawater
    - Pump through wellhead valves
- Install plug at 420m and 128m in prior to remove XMT
    - Executed with wireline

At this point, the conventional rig tower does the rest of P&A operation, with the exception of logging.

- Nipple down XMT.
- Nipple up BOP.
- Recover 5 ½ inch and 5 inch production tubing.
- Restore seal #9 in 7 inch liner.
    - set cement plug inside 7 inch liner.

P&A phase 2

- Clean out & log $9^{5/8}$ inch casing.
- Restore seal #8 in $9^{5/8}$ inch casing.
    - Executed by using PWC method.
- Restore seal #7 in $9^{5/8}$ inch casing.

    - Executed by using PWC method.
- Restore seal #6 in $13^{3/8}$ inch casing.
    - Executed by section milling and cementing.
- Restore seal #2 in $13^{3/8}$ inch casing.
    - Executed by section milling and cementing.
- Remove c-section on wellhead.
- Cut and recover $9^{5/8}$ inch casing.
- Clean out and log $13^{3/8}$ inch casing.
- Remove b-section on wellhead.
- Recover $13^{3/8}$ inch casing.
- Install surface barrier.

This program from 2015 shows how complex the P&A operation can become when there are many different permeable zones. The seals listed in this program represents different permeable zones. One has to cut and recover several casings. The program also shows that some of the initial operations are performed with wireline and coiled tubing.

It can be noted that the operations are performed using a jack up rig because the original rig tower was removed in 2009 [37].

Rigless P&A Concept.

We need to distinguish between two types of oil wells: Subsea wells and those connected to fixed structures like steel platforms or condeep platforms.

For subsea wells, the rigless approach aims to figure out how to do certain operations, like plugging and abandoning the well, using smaller and more mobile ships [2].

With wells on fixed platforms, the focus is more on avoiding the big drilling tower and instead moving some of the work/activities to smaller equipment like wireline, coiled tubing, or hydraulic jacks when needed. In some cases, the big drilling tower has been taken away, and the goal is to hold off on renting a specialized drilling rig until it's necessary for the more complex parts of the plugging and abandonment process.

Technologies for Rigless P&A on Fixed Platform

Wireline

Wireline is a method for running tools with wire into a wellbore, primarily relying on gravity. Wirelines are strong, thin wires mounted on a powered reel. It consists of small modules with high flexibility and low rig-up time. Wireline be rigged up as standalone with wireline mast, through coil tubing tower or through the drilling derrick.

Surface equipment consists of wireline unit with the wireline drum, pressure control unit with pumps

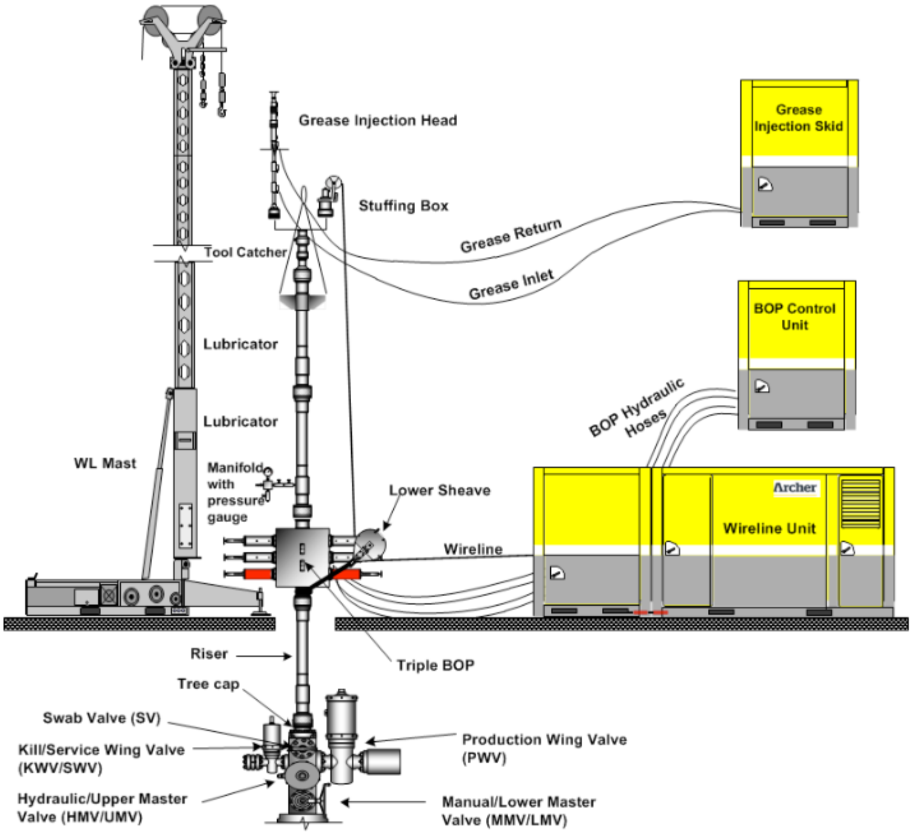

Figure 5 – Typical wireline configuration [8]

and panels, upper and lower sheave, stuffing box, lubricator and wireline rams. Figure 3 shows a typical wireline setup with wireline mast.

Wireline consists of four different cables. Slickline, braided line, multi-conductor, single conductor.

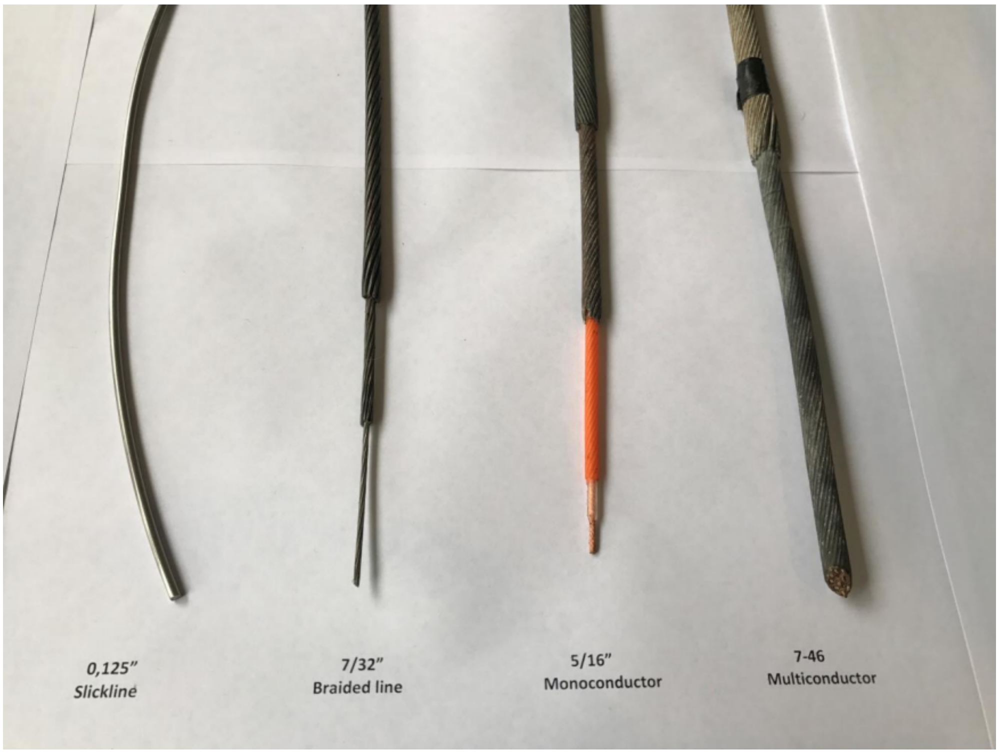

Figure 6 – Different types of wireline wires [8]

In this thesis, wireline will be referring to all cable operations.

Wireline can perform these P&A operations [28]:

- determine the status of the well. Logging temperature, pressure and do a caliper run
- cut the tubing
- set/pull temporary shallow plug

Wireline units have max pull of around 7 tonnes.

WL Tractor

The tools are lowered into the well relying on gravity. This was a major weakness in horizontal and deviated wells. The only options where to use the rig tower, coiled tubing or snubbing units. Then came the 90's and the wireline tractor was released. This was a huge breakthrough!

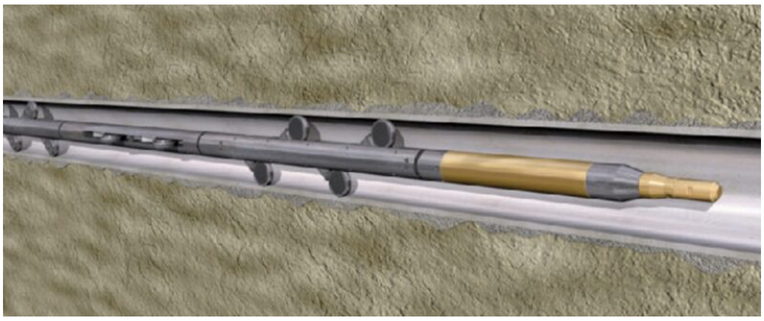

Figure 7 – Wireline tractor [9].

With this self-propelled robotic device, wireline tool strings can be pushed to the end of the wellbore [9].

Coiled Tubing


Figure 8 – Coiled tubing reel and injector with gooseneck [18]

Coiled tubing is another type of well intervention technology. It consists of a flexible pipe that is spooled on and of a reel by the injector head. The pipe diameter is usually between 25mm to 83mm [10]. Coiled tubing can carry out the same work as wireline, but it is bigger. The advantage over wireline is that fluids can be pumped through the reel and since it is bigger, it is stronger so it can carry out more heavy work. The disadvantage over wireline is since it is bigger, coiled tubing requires more power to operate, longer rig-up/rig down time. The reel usually weighs 40-50 tonnes. This is around the max limit of the offshore rig crane. When the reel is being lifted on or off the supply boat, it is categorized as a critical lift. A job safety analysis (JSA) is required for every critical lift offshore. This results in more time used during rig up and more strict requirements for weather during the lifting process.

Compared to wireline, the coiled tubing can be used to set cement plugs and has larger pulling capacity. It has typically around 35-45 tonnes max pull [38, 39]. It can also be combined with PWC technology. This will be described later in this thesis.

Hydraulic Workover Unit

HWO units has been on the market for quite some time. The origin of HWO is dated back in the 1920's as the need of an efficient well servicing tool that could handle surface pressure was rising [21]. A good overview of the different types of HWO was provided by [22].

There is a lot of different HWO units on the market. These HWO units are built up by modules, so how the HWO unit is built is depending on the type of work that is needed.

Looking at the lowest range of HWO units, these units is pure jacking unit. This means that the unit can run in and out of a well with pipe (drill pipe, tubing, casing, conductor) but do not have well control equipment. They can only work on "dead" wells that have been plugged or has the minimum requirements of barriers. An example of this type of unit is Wellraizer by Claxton, which is described in the next section.

Going further up in scale, HWO units can rotate and pump through pipe and have well control equipment. They can even be equipped with a top drive and perform section milling.

Many HWO units can "snub", which means running a drill string in a live well with surface pressure. This is why these HWO units usually is called "snubbing" units.

An example of the biggest HWO unit is WellGear 600K P&A [26]. This unit is special designed for doing P&A from start to finish as it did on Brent Charlie in the UK sector [22].

HWO units was commonly used on the NCS up until the beginning of 2000's. Then they vanished due to new regulations regarding HSE. These regulations were removing people from red zone and introduced remote pipe handling. And since the HWO units is lacking remote pipe handling systems they were not allowed on the NCS [27].

HWO units is commonly used on British sector.

Wellraizer

Figure 9 – Wellraizer on a wellhead platform [19]

This is a hydraulic jack system built specific for well interventions and P&A. It is a rigless well recovery system. This system is delivered by Claxton, an Aceton company. Wellraizer is designed with NORSOK in mind, so it is fully compliant to be used on the NCS. This hydraulic jack can handle conductor pipes and casing of up to 36 inch in diameter. In the biggest configuration the lifting capacity is 300 metric tonnes and can handle a length of 12,2 meters. It is small and compact compared to its lifting capacity and can easily be fitted on an unmanned platform. It is designed in lightweight modular units with no component weighing over 10 metric tonnes. It is a flexible unit that can skid in two directions to access multiple wells on the same platform. Wellraizer is driven by its own diesel generator, so it is not dependent on the rig power supply [7].

Statfjord Hydraulic Jack Project

Equinor is seeing the potential of doing P&A with HWO unit on Statfjord A. This is a project where they want to use a light weight pulling unit for P&A. When using a HWO, it allows for later shut-in for wells, which brings the overall cost down [35]. It is designed to be mounted on the skid beams for the conventional rig tower.

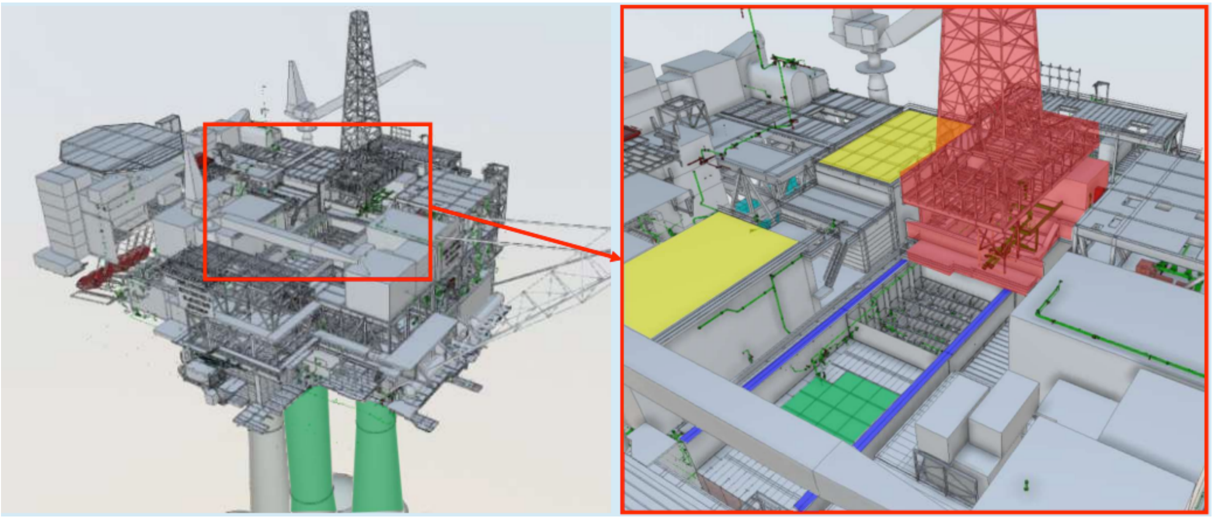

Figure 10 – Statfjord A. Skid beams in blue, derrick in red, pipe deck in yellow and green is where the wells are located [35]

The lift capacity is planned to be 150 tonnes with a lift height of 14m. It shall have pumping capability, but no top drive. It is planned to have a fully automated pipe handling system. The max tubular size it can handle is 7 $^{5/8}$ inch. It will not have the ability to rotate [35].

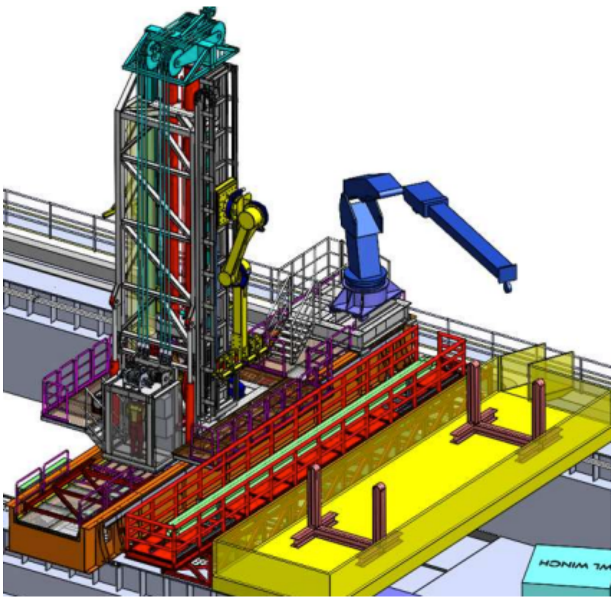

Figure 11 – Blueprint of the pulling unit. The yellow combined with the blue crane is the automated pipe handling system [35]

WellGear 600k P&A

WellGear 600K P&A [36] is the biggest HWO WellGear can offer. 600k means max pulling capacity of 600,000 lbs (272 tonnes). This HWO can pump fluid and rotate pipe, so it is fully suitable for e.g. section milling. This unit also has well control equipment, so it can work on wells with pressure or when there is risk for an influx. This HWO is specially designed to do P&A from start to finish.

The types of HWO's that WellGear can offer are commonly used on British sector but are not in use on NCS due to safety regulations regarding red zone and the lack of fully automated pipe handling [27].

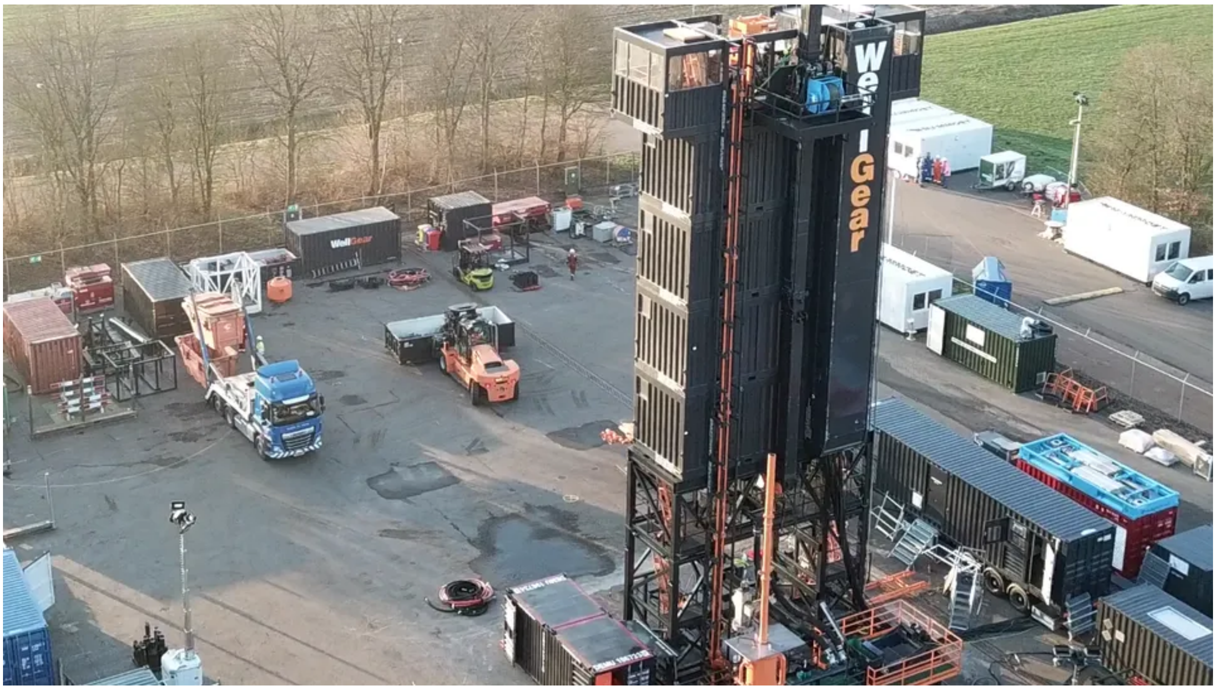

Figure 12 – WellGear 600K P&A at WellGear's yard [36]

Modular Rig

Modular rig is the closest to a conventional drilling rig. These modular rigs have all the equipment to do regular drilling jobs, well intervention or full P&A. They are built up by modules and the standard modules are 6mx3mx3m(LxWxH) and weighs around 12 tonnes. Some modules are unsymmetric and can weigh up to 30 tonnes.

The modular rig consists of four units.

- Power supply control rooms HVAC
- Drilling rig
- Mud package hydraulic unit
- Pipe deck

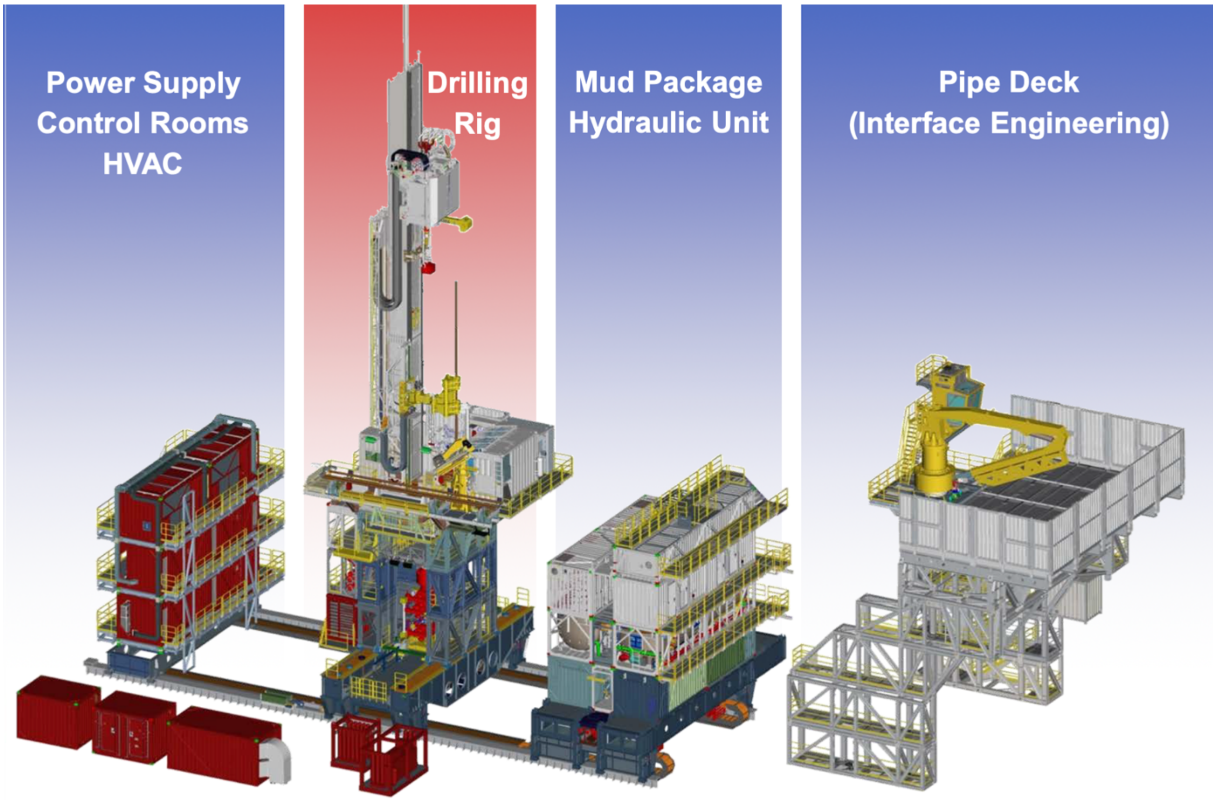

Figure 13 – Modular rig with all packages [33]

The max lift height on the drilling rig is 19m and max pull is 363 tonnes. It has a top drive so it can rotate and pump at the same time. It has a complete well control system including trip tank, degasser and BOP with choke and kill manifold.

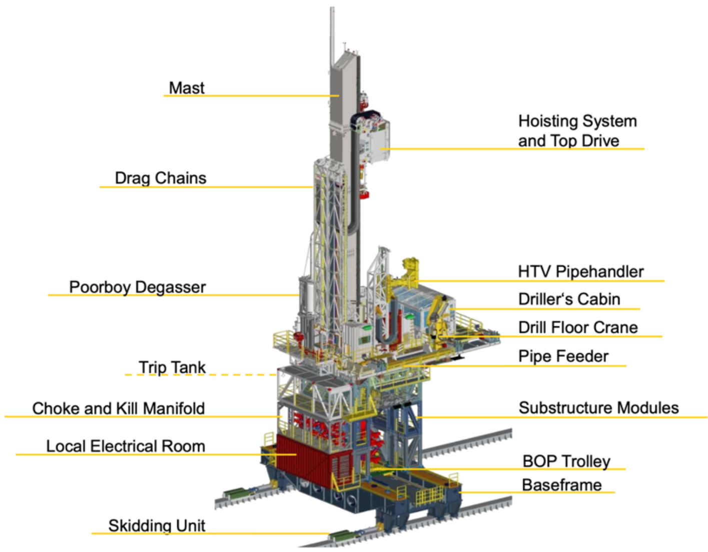

Figure 14 – Overview of Archer's Modular drilling rig [33]

Downhole Equipment for Aiding P&A-Operations

When performing P&A, surface equipment is limited to what the downhole equipment is capable of. Development of new technology in downhole equipment is important today and will be in the future as well because this can lead to more rigless work.

Logging Through Multiple Casings

P&A is all about confirming or establish barriers where it is needed. That is why logging is a crucial operation in all wells that is being P&A, to get a clear picture of the barrier behind tubing/liner or casing. In many cases, tubing/liner and casing needs to be retrieved to log behind. The traditionally approach to cement or barrier logging will require to remove the inner pipe to log behind the other. Ex. To confirm cement behind $9^{5/8}$ inch casing, the 7 inch production tubing needs to be retrieved. Depending on the complexity of the well, this is an expensive and time-consuming operation.

A breakthrough has come in this segment. SLB offers Epilogue™ dual-string barrier evaluation tool. This can log through 2 pipes in one single run. This is a huge advantage and saves a lot of in-well runs, which saves time and therefore reducing cost. As a bonus, the carbon footprint is smaller [13].

According to the case study [14] for P&A on Hewett Field (UK sector), they avoided a complex pulling and milling of $13^{3/8}$ inch casing section, resulting in saving 42 rig days and 670 metric tons of CO_2.

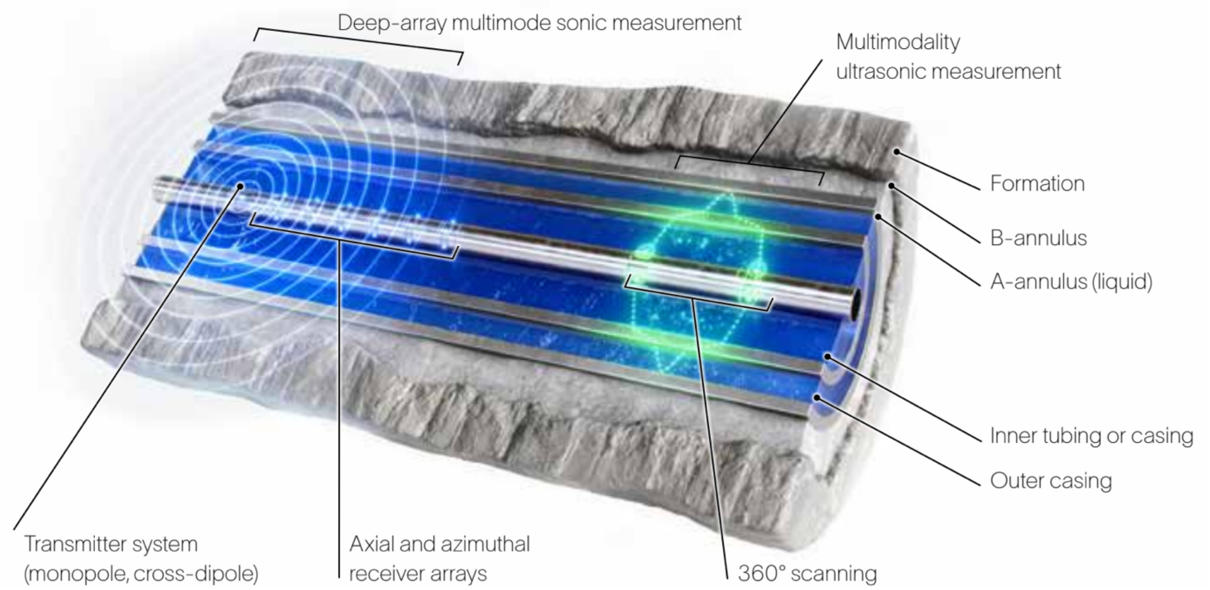

Figure 15 – Logging through multiple pipes with the dual-string evaluation tool [13]

Epilogue™ is a tool with outer diameter of 3.625 inch. It can withstand a pressure of 137895 kPa and a temperature of 177°C. The minimum tubing it can run log through is $5^{1/2}$ inch with inner diameter of 4 inch and can log up to $13^{3/8}$ inch casing. But maximum 2 pipes at once.

Radial Cutting Torch

Radial Cutting Torch (RCT) is a wireline tool by Archer, designed for efficient pipe cutting up to $9^{5/8}$ inch without explosives or hazardous chemicals. The tool can cut tubing, casing, drill pipe and coiled tubing. One uses advanced technology combined with carefully designed jet nozzle, to create high energized plasma that can cut any type of pipe in any well condition. Since it does not use explosives or hazardous chemicals, the tool can be shipped almost anywhere within 24 hours [30].

How it works

The RCT is lowered into the well until desired dept is reached. Then the Thermal Generator ignited and activates the primary fuel load. Highly energized plasma is produced, causing an increase in internal pressure. Once the pressure inside the torch exceeds the pressure of the wellbore, the protective sleeve is displaced, exposing the nozzle to the wellbore. Plasma exits through the nozzle and cuts the pipe.

Figure 17 – Cuts made with the RCT [30]

Figure 16 – Components of the Radial Cutting Tool [30]

Downhole Pulling Jack

If a fish is stuck somewhere in the well or casing needs to be pulled, sometimes it can be hard to get it loose. E. g. casing can be quite stuck due to settled barite. Often the casing needs to be cut in smaller segments to be pulled because the limitations of the drilling equipment e.g. drill pipe, top site equipment. One solution to this is Ardyne downhole power tool. This hydraulic downhole jack can put an extra pulling force from 51 tonnes up to 789 tonnes, depending on the size of the tool [15].

The unique about this tool is that it puts pulling force directly to the fish avoiding high tensile forces on the workstring (drill pipe) and surface equipment. This makes the operation safer and more effective. This also allows for smaller top site equipment to perform heavy duty pulling. For example, a hydraulic jacking unit.

How it works

With Ardyne downhole power tool bottom hole assembly (BHA), it can cut and pull casing in the same run and even do multiple cuts. Below is an example of how it works after a casing has been cut, and it is time for it to be pulled.

First, the TYPHOON spear enters the casing. Then the slips in the spear is engaged to the casing joint that shall be pulled. First attempt to pull casing with rig. If this does not work, the slips on downhole power tool are engaged. But before engaging, the rig pulls as much as it can (example 200 tonnes). Then the slips are engaged above the casing joint that is being attempted to pull. Now without lowering the tension from the drilling ring, the power tool pulls with extra power directly on the casing joint. If the power tool pulls with ex 400 tonnes, then the total pulling force on the casing joint is 600 tonnes (200 tonnes from rig and 400 tonnes from the power tool).

Figure 18 – Downhole Power Tool [15]

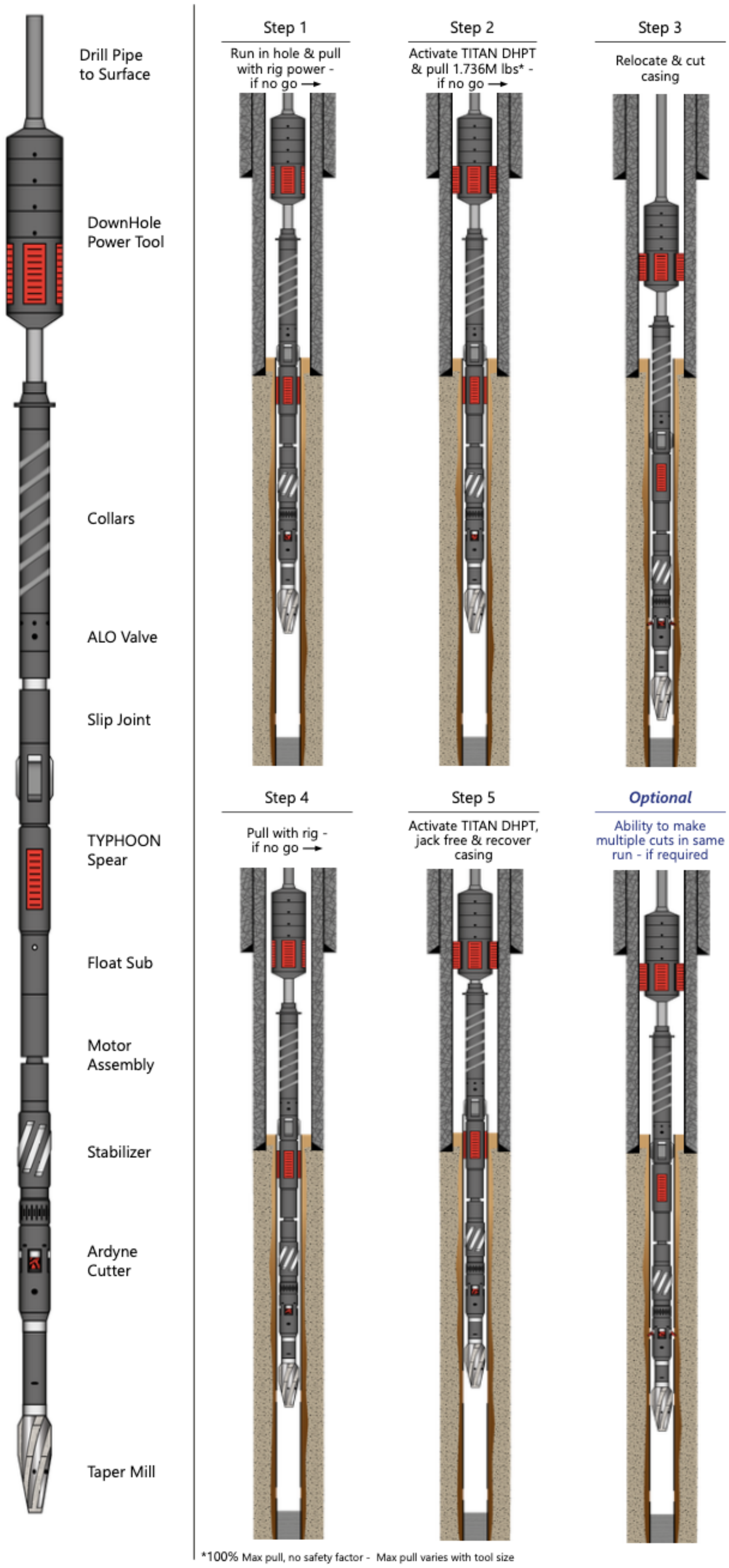

Figure 19 – Visualization of a cut and pull run with Ardyne downhole jack [15]

HydraCT™

HydraCT™ is a new development by HydraWell for the PWC technology. HydraCT™ is the first system for doing PWC for rigless abandonment. This is a self-rotating, jet-propulsion tool ideal for coiled tubing when there is no ability to rotate the workstring or the is ID restrictions or limited load restrictions.

Figure 20 – The components of HydraCT™ tool [29]

How it works

One complete operation consists of three runs. First a plug is installed as a base for the upcoming cement job.

The barrier interval section is perforated during the second run.

On the third and final run, the self-rotating, jet-propulsion tool assisted by the diverter begins to clean out debris from behind the casing. Then the tool is repositioned at the bottom of the perforated interval to place the spacer. After that, the tool is again repositioned at the bottom of the perforated interval to place cement.

After cement has hardened, it is tagged and pressure tested [29].

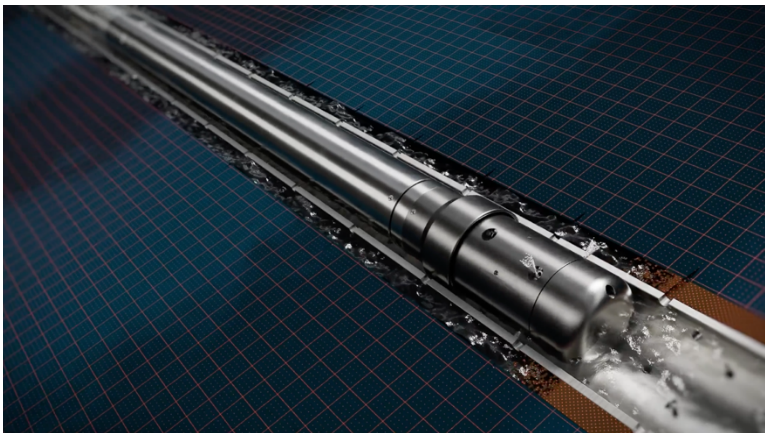

Figure 21 – It is the lowest part of the tool (up till the first collar) with jet nozzles that rotates [29]

Slot Jet Isolate

Slot Jet Isolate (SJI), by Titan Torque services Ltd, can be used as an alternative to PWC for reestablishing barrier and to clean behind stuck casing. The main difference here is that this tool does not use explosives. It uses a special designed sprocket with curved teeth that is pushed out to the sides of the casing, perforating while pushing the tool downwards. Because of the curved teeth, the perforated holes in the casing is angled/curved allowing to direct the jetting around the backside of the casing.

Figure 23 – Casing after Slot Jet Isolate [23]

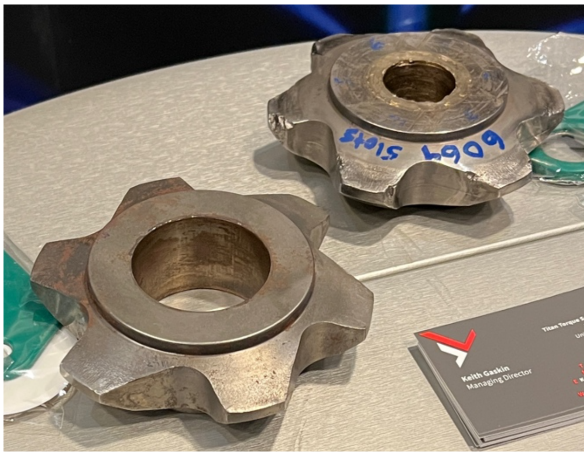

Figure 22 – Specially made sprockets used for Slot Jet Isolate [23]

While the tool is slotting(perforating) the casing, the jet nozzles located above (and below) the sprockets can be activated allowing it to clean behind the casing at the same time. After the casing is sufficiently washed on the inside and outside it is ready to place cement, or the casing is ready to be retrieved to surface. The tool comes in different sizes. The smallest casing it can Slot Jet Isolate is 7”.

Compared to PWC, where explosives are used, there are strict rules when transporting. Special competence by the personal handling the tools before, during and after transportation is required. And when handling the BHA, it is required to set up barriers around the drill floor and all the way down to the wellhead.

Since the SJI method does not use explosives, it is cheaper and safer to transport the tools and when handling the BHA, one does not have to barricade from drill floor and all the way down to the wellhead.

As for now, this tool can only slot downwards. The company is working on the ability of slotting upwards for the intended use for rigless technology [31, 32].

Conclusion

Considering the large number of wells that needs to be PP&A on the NCS, it is important to explore untraditional ways for doing P&A.

For a long time, wireline and coiled tubing has been an important part at the start of P&A operations. But as shown in this thesis, operations that wireline and coiled tubing can perform have expanded.

Wireline, which is the smallest of the surface technologies, can be used for lighter P&A operations like logging, cutting tubing and set/pull shallow plugs. This is how it is used today. But wireline can cut casing all the way up to $9^{5/8}$ inch.

Coiled tubing is a step up in surface equipment and is being used for killing wells, displacement of fluids, set and retrieve temporary plugs and set cement plugs. New development in downhole equipment makes it possible to apply the PWC method in combination with coiled tubing. This will be an alternative to milling in cases when the cement behind casing is not acceptable. Meaning the cement plug does not seal both vertical and horizontal to prevent HC migration.

In many cases the tubing and casing needs to be cut and retrieved, especially if the tubing has control lines and if there is bad cement in the annulus behind the production casing. This is due to the risk of HC migration alongside the control cables or migration of HC past an old cement barrier. This cannot be done with either wireline or coiled tubing. Usually this is where the conventional rig tower comes in and does the job. And in case, the original rig tower has been removed, one need to hire a jack up rig to perform the task. However, in case the tubing can be left in the hole and since we now have started to be able to log through several casing, one might reduce the need for the conventional rig tower. Since one then will be able to log the cement behind the production casing without having to pull the production tubing.

If the casing is stuck due to settled barite it can be a problematic operation, even for the conventional rig tower. If the rig cannot pull the casing, standard procedure is to cut the casing in smaller and smaller pieces until it comes loose. Ardyne has invented a downhole jacking tool to aid in this operation, making it easier to pull larger pieces of casing with greater pulling force while lowering strain on surface equipment. The SJI method, which is a great alternative to PWC, can also aid in this operation by washing behind the casing.

There is a big gap between coiled tubing and conventional rig tower in what types of well operations they can do, and here is where the HWO units and modular rigs comes in.

The variation in HWO units is big, so they can be built after purpose. They can be as simple as a pure lifting/jacking unit with no well control equipment, all the way up to pulling 300 tonnes and be equipped with a top drive for rotation and pumping fluids with well control equipment.

The technologies to do complete P&A without a conventional rig tower exists today. Wireline, coiled tubing, HWO units and modular rig in combination with the development in downhole tools, is fully capable of doing P&A from start to finish. However, it is crucial to acknowledge that certain challenges still exist, particularly on the NCS, with the lack of automated pipe handling systems for HWO units. This limitation needs attention for future progress. If automated pipe handling systems can be added to HWO units, it would make it easier to use rigless methods for abandoning wells instead of the conventional rig tower and could possibly be the new industry standard. The competence for building these units is available but it requires financing to build these. Perhaps a closer cooperation between operators and vendors are needed to have financial models that can support the development of HWO's adapted to NCS.

With the added pipe handling systems for HWO's, this can become the new industry standard for P&A, offering more flexibility, reduce operational and carbon footprints, and lead to considerable savings.

The complexity of a P&A operation can vary substantially. The most complex operations will be when one has to plug several permeable zones and where casing have to be cut deep and retrieved afterwards. If there is a need for milling, this will also complicate the picture. It is clear that for simpler prospects, it will be much easier to perform the P&A operations without a rig. But also, for the more complex scenarios, it seems that the technology for performing most of the P&A operations without a rig are available.

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