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UNIVERSITI TEKNOLOGI PETRONAS

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by

MUHAMMAD HAZIQ BIN MD JAAFAR

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OPTIMIZATION FOR WORKOVER AND PARTIAL PLUG AND ABANDONMENT (P&A) ACTIVITIES AT FIELD A

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MUHAMMAD HAZIQ BIN MD JAAFAR

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MASTER OF SCIENCE

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PERAK

DECEMBER 2023

DECLARATION OF THESIS

Title of thesis: OPTIMIZATION FOR WORKOVER AND PARTIAL PLUG AND ABANDONMENT (P&A) ACTIVITIES AT FIELD A.

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ABSTRACT

The project is solely on the research purpose and the lesson learn that can be capture from the workover and partial P&A activity at Field A operated by the PETRONAS Carigali Sdn Bhd PCSB. The optimization are in term of planning, design and execution for the whole project. The workover and partial P&A activity is very common in the oil and gas industry as currently there are a lot of depleted hydrocarbon reservoir especially at Malaysia region hence required for the wells to be workover to enhance the hydrocarbon recovery. Expensive rig cost in term of Operating Daily Rate (ODR) makes rig selection to be a crucial component in any E&P activity especially at offshore shows how by planning optimization can reduce rig time. Offline activity has not been emphasised enough on how it will give a good impact to any project in term of rig time and cost. Tools and equipment failure has cost fortune as it produces Non-Productive Time (NPT) in the operation and may cause the project to complete after the deadline shows the important of design optimization. Therefore, the objective of this paper are divided into 3 main component respectively which are to determine the optimum rig selection for workover and partial P&A activity that is compatible for the operation and maximize the cost saving, to determine and maximize offline activity that can be done prior to rig up and lastly to propose and justify any new technology for tool selection in the operation that is more efficient and reliable. The methodology or workflow from this project are from study case and record lesson learn from the operation, which various article have been review and analyse to come out with the planning, design and operation optimization. Overall, the objective of this project is achieved which the optimization of workover and partial P&A activities at field A. Next, for rig selection, cost and capability of the rig have been compared and it shows Semi TAD has shown the best criteria for the partial P&A and workover operation at Field A. In term of offline activity which are cut the tubing and set the tubing plug has cut the rig time for approximately 38 hours and save cost for approximately 316,000.00 USD. Lastly, there are 3 new or existing technology have been proposed in this paper which can help to ensure better project execution for future use.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND NOMENCLATURES

ADIR	Asset Development Integrated Review
ALARP	As Low As Reasonably Practical
APB	Annulus Pressure Build Up
BCP	Balance Cement Plug
BHA	Bottom Hole Assembly
BOP	Blowout Preventer
CAPEX	Capital Expenditures
CCS	Carbon Capture Storage
CDFT	Critical Device Function Test
DES	Drilling Equipment Set
DVA	Direct Vertical Access
E&P	Exploration & Production
ESP	Electrical Submersible Pump
FEED	Front-End Engineer
HWU	Hydraulic Workover Unit
JUR	Jack Up Rig
MDDF	Measure Depth Drilling Floor
MMscf/d	Million Standard Cubic Foot Per Day
MMV	Measure, Monitor And Verification
MODU	Mobile Offshore Drilling Units
MPM	Malaysia Petroleum Management
NNW	North Northwest
NOWOP	Notice Of Workover Program
NPT	Non-Productive Time
ODR	Operating Daily Rate
OEE	Overall Equipment Effectiveness
OPEX	Operating Expenditure
P&A	Plug And Abandonment
PCSB	Petronas Carigali Sdn Bhd
POOH	Pull Out Of Hole
PPGUA	PETRONAS Procedures And Guidelines For Upstream Activities

R/D	Rig Down
R/U	Rig Up
RIH	Run In Hole
ROI	Return Of Investment
Semi-TAR	Semi Tender Assisted Rig
SIMOP	Simultaneous Operations
SME	Subject Matter Expert
SOP	Standard Operating Procedures
SSD	Sliding Sleeve Door
SWAP	Subsurface Well Abandonment Plan
TDS	Top Drive System
WOW	Wait On Weather
WSRP	Workover Rig Scheduling Problem

CHAPTER 1: INTRODUCTION

1.1Background

Field A is an old producing field operate by Sarawak Shell Berhad where it first gas was in March 1996, and it has produce for almost 30 years. The existing platform, consist of 12 wells where 3 well is an empty slot, 5 wells will be fully plug and abandon (P&A) and 3 wells will be under workover team for the future operation. The 3 wells are then divided which 2 well will be partially plug and abandonment for sidetrack operation and 1 well will be recomplete and remedial as the well will be convert into Measure, Monitor and Verification (MMV) well which support Kasawari Carbon Capture Storage or known as Kasawari CCS Project.

The field A located 275 km NNW away of Bintulu and it was developed together with another campaign in 1995/96 as Phase I of MLNG Dua and came on stream in March 1996. The development was designed to meet an initial gas demand of approximately 720 MMscf/d (later expanded to 800 MMscf/d) of dry gas and initially consisted of eight wells i.e. seven deviated producers and one vertical water disposal/observation well.

The wells P&A drivers at field A are:

- To convert the existing platform to carbon storage platform that will receive CO_2 from Kasawari field.
- Prior to CO_2 injection, all unused wells on A-platform are required to be P&A.
- To reduce operation cost exposure of maintaining unused wells on A-platform.

There are 2 activities that will be focused on this paper which are the workover and partial plug and abandonment (P&A) activities. The campaign that is currently on going at this field A is full P&A operated by the PCSB to support the Kasawari CCS project. An overview of the workover operation encompasses the whole lifecycle of oil and gas field development and is at the heart of routine oil and gas well production, management, optimization, and maintenance. Workover entails a massive company system with daunting tasks and a large workforce size. The total number of oil, gas, and water wells for PetroChina Co. Ltd. (hereinafter referred to as PetroChina) is 36*104, with workover operations using a significant amount of people and material resources each year [1]. Workover operations are critical to sustaining regular operations and stabilizing and boosting output in oil and gas fields.

The second activity that will be focus on this paper is partial P&A which at field A there will be 2 wells undergoes partial P&A while the other 5 is permanent P&A. There are various reasons to done wells partial P&A such as for sidetrack, to partially isolate the reservoir and convert the well into water injection or donor well. Since this project involved P&A activities, the operation always needs to align with Subsurface Well Abandonment Plan (SWAP). As per PETRONAS Procedures and Guidelines for Upstream Activities (PPGUA) 4.1 Vol 7 Sec. 9, SWAP is an official document issued by PETRONAS certifying the well abandonment shall take place either for partial or permanent well abandonment [2].

9.4 Application to Abandon a Well

Except for exploration wells, all other wells shall require the SWAP certificates. The approved certificates are required prior to performing any well abandonment (SWAP-1) or using the wellbore for future utility such as sidetrack or slot recovery (SWAP-2A and SWAP-2B). Further details on the requirements and procedures to obtain SWAP certificates shall be referred to Volume 8, Section 2.

Figure 1.1: Application to Abandon a Well Based on PPGUA

Based on the figure above, it shows that prior to commencement of any activities related to the P&A activity either permanent or temporary it required a permission from the Malaysia Petroleum Management (MPM) from PETRONAS as the owner of Malaysia field in oil and gas industry. There are 3 types of SWAP which will be discussed more in the Literature Review chapter regards to the definition, example and application based on the activity of the P&A as a whole.

1.2 Problem Statement

Workover and Partial P&A activity is very common in the oil and gas industry as currently there are a lot of old oil and gas reservoir which is already depleted hence required for the wells to be workover to enhance the hydrocarbon recovery. As PetroChina's exploration and development practices shift toward "low-permeability, deep-burial, marine, and unconventional" resources, the diversity of oil and gas reservoir types expands, and the wellbore structure becomes more complex. As a result, the criteria for safety and environmental protection are growing more stringent, and more new obstacles develop in the implementation of workover. Medium and high permeability mature oil fields are primarily found in eastern oilfields like Daqing, which have generally reached the "high water cut and high recovery degree" stage. Given this, it is vital to maintain reasonably consistent production. Workover operations involve wellbore scale formation, corrosion of production tubing and casing, and casing failure due to the extended recovery time and rising water cut [1]. Hence, the safety, complexity and cost will always be the major factor for the whole operation in oil and gas industry include the workover and partial P&A activities.

1.3 Objectives

There are 3 objectives from this paper in term of planning, design and operation optimization for workover and partial P&A activities at field A which are;

i. To determine the optimum rig selection for Workover and partial P&A activity that is compatible for the operation and maximize the cost saving.
ii. To determine and maximize offline activity that can be done prior to rig up.
iii. To propose and justify any new technology for tool selection in the operation that is more efficient and reliable.

1.4 Scope of Study

The scope of this paper is to study and determine any opportunity that can be optimize in term of planning, design and operation for workover and partial P&A activities at field A only. The scope for workover and partial P&A activity is very wide hence limited to the 3 objectives of this paper only which is the rig selection, optimize offline activity and tool selection that ultimately will increase the efficiency of the operation, cut the operation time, and save the cost that will give benefit to the company itself.

For the first objective which is to determine the optimum rig selection for Workover and P&A activity that is compatible for the operation and maximize the cost saving is only to compare between 4 most common rig use for workover and partial P&A activities which is the Hydraulic Workover Unit (HWU), Jack Up Rig (JUR), Semi Tender Assisted Rig (Semi-TAR) and drillship. This comparison is in term of cost and compatibility of the rig whether it is suitable to be use for the designated operation or not. This is more prone towards to the planning optimization

Next, the second objective is to determine and maximize offline activity that can be done prior to rig up is to identify and figure out is there any offline activity that can be done at field A prior to the rig up. This paper is limited to the workover and partial P&A activity at field A only whereas there are a lot of offline activity can be done but limited to the equipment availability at the platform. Basically, this offline activity can reduce the rig time, hence the cost for daily rig rent can be cut based on the time of offline activity. The longer the offline activity that can be achieve, the less time on rig hence higher cost saving for the whole operation.

Lasty, the third objective is to propose any new technology on tool selection that can give better success rate of the operation and increase the efficiency of the operation. This last objective is for design optimization for the whole activity at Field A. The tools that will be proposed are packer, overshot and milling tools. This can reduce the Non-Productive Time (NPT) which ultimately give 100& productive time to complete the whole project within the timeline as planned of the campaign at Filed A. This tool selection is only limited to the tools used during this campaign at Filed A.

CHAPTER 2: LITERATURE REVIEW

2.1 Overview Workover

Workover operation is any activity that conducted with equipment and support facilities that include requirement for a rig over a wellbore. The main different between workover operation and well intervention is the requirement to nipple down the Xmas tree and nipple up the BOP to retrieve the tubing. Well intervention in a nutshell is any activity the required to go into the well either the well is flowing or shut in such as fishing, wellbore clean out and open or close the Sliding Sleeve Door (SSD) at completion tubing. There will be 2 sub chapter from this workover, which is the definition of the workover itself and the typical procedure of workover which is the general until retrieve the tubing out of the wellbore.

2.1.1 Definition

Workover technology is the technical process by which experts perform wellbore maintenance and repairs using specialized instruments and equipment in compliance with technical plans that are reliant on the rock in the reservoir characteristics and state of the water, gas, or oil well [1]. Workover is typically necessary to ensure the regular production of gas, oil, and water wells in order to complete activities like "wellbore repair, dealing well downhole malfunction, and adjustment of producing layers."

Following well drilling, the formation is assessed to determine whether commercially viable oil is present. If so, the well is finished and put into service. The well's original circumstances may alter at some point during its producing life, which might result in a reduction in the well's performance or an integrity problem that would make it hazardous for the well to continue producing. If there is still a sizable amount of hydrocarbon in the reservoir, the well needs to be repaired or its performance needs to be enhanced in order to resolve the integrity problem and make the well safe for production.

In the Schlumberger Oilfield glossary Well Workover and Intervention is defined as follows “The process of performing major maintenance or remedial treatments on an oil or gas well. In many cases, workover implies the removal and replacement of the production tubing string after the well has been killed and a workover rig has been placed on location. Through-tubing workover operations, using coiled tubing, snubbing or slickline equipment, are routinely conducted to complete treatments or well service activities that avoid a full workover where the tubing is removed. This operation saves considerable time and expense” [3].

At Offshore-technology.com workover is defined as follows “Workover is a term used to describe operations on a completed production well to clean, repair and maintain the well for the purposes of increasing or restoring production” [3]. At field A the objective for workover for 1 of the wells is to recomplete which is once all the completion Bottom Hole Assembly (BHA) and production tubing is being retrieve from the wellbore and Pull Out of Hole (POOH) to the surface, there will be a sidetrack activity from the well there. There is the reason this paper focus on 2 activities which is workover and partial P&A activities. The partial P&A activities will be discuss more on the next sub chapter of this paper.

Rarely are there any rules in place for well intervention units. Due to the nature of the equipment required for well intervention, these activities can be performed on nearly any vessel that has a heave compensated crane. There may be significant differences in the activities carried out and the equipment utilized. Not to mention the fact that every well will have unique properties. However, this is typically not considered in regulations pertaining to vessel design. This indicates that the industry itself regulates well intervention unit needs in various parts of the world.

Thus, the phrase "workover" may have different meanings to different people. Heavy handling equipment is required when workover/well intervention is employed in a context where physical modifications to a well or replacement of production tubing are required [3]. These operations entail working toward an open well using a riser equipped with a Blowout Preventer (BOP), mud barrier, and circulation system. Most often, drill ships or drilling semi-submersibles also known as mobile offshore drilling units (MODU) are used for these kinds of activities. These units have been in existence for a considerable amount of time, and although country-to-country variations exist in the legal frameworks governing drilling units, these operations are often subject to established regulations.

2.1.2 Procedure

There is variety objective of workover operation whether want to add Electrical Submersible Pump (ESP) which is one of the examples of artificial lift to increase flow rate when reservoir has no energy to lift the hydrocarbon to the surface, repairing the wellbore that required to POOH the tubing or recomplete the well. In further clarification, workover operations are those that entail completing, maintaining, and repairing downhole production equipment in a well that has already been finished which is a production well. In addition, workover is useful in carbon capture and storage, where it is intended to restore the integrity of existing wells and convert them to CO2 injection or observation wells.

There are no Standard Operating Procedures (SOP) for workover operation as it depends on the objective of the operation. In any oil and gas activities, safety will always be a priority hence the requirement from the PETRONAS to always have minimum 2 barrier for the whole operation of Exploration & Production (E&P) which workover included [2]. Every operation at the Malaysia region included onshore and offshore that is related to oil and gas industry require to have the approval from the Malaysia Petroleum Management (MPM). Over the course of the upstream oil and gas asset lifetime, PETRONAS has entrusted MPM with the overall administration of Malaysia's petroleum resources in other words act as the owner of the land for hydrocarbon resources in Malaysia. Since the founding of PETRONAS in 1974, MPM has governed the nation's petroleum development.

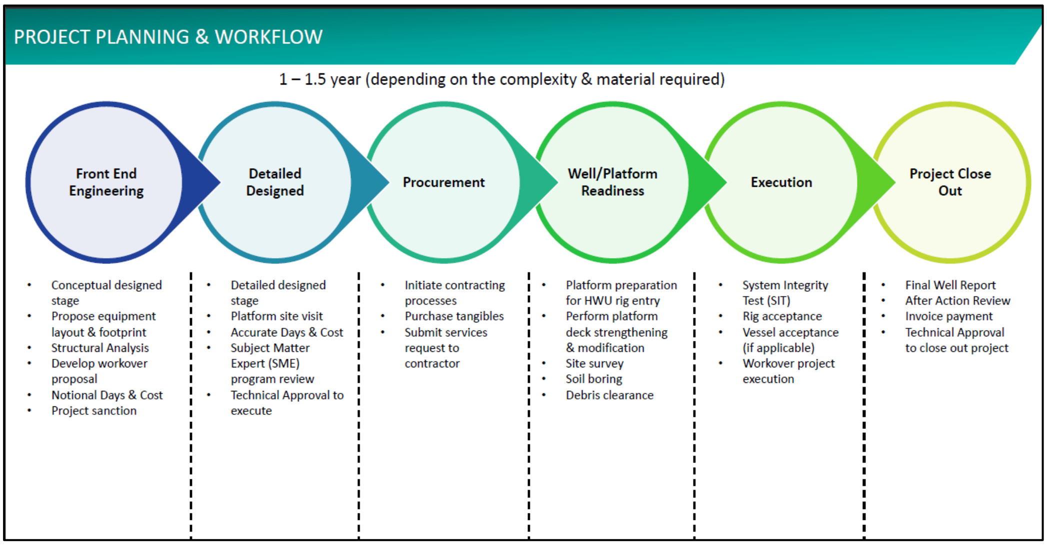

Figure 2.1: Project Planning & Workflow for Workover Operation

Based on the figure it shows how a typical project planning and workflow for the workover operation where usually it will take up to 1 to 1.5 years depends on the complexity and the material required for the operation. It involves not only the team from the workover team only, but it involves the other team such as the Front-End Engineer (FEED) to develop the conceptual designed stage, the Subject Matter Expert (SME) from the well intervention, well completion and well engineering respectively to give a validation and assurance in the project from the design to the execution phase.

Workover operation is as crucial as any E&P operation as it ultimate objective is to give profit to the organization itself. Based on the figure, there are 6 stages of the project planning and workflow of the workover operation from front end engineering to the project close out. Currently at field A it is a stage 5 which is the project execution hence the monitoring of the project is ongoing daily. All activities performed at the rig must be recorded daily from the first day execution until the end of the campaign and the level of details as specified as PETRONAS [4]. This daily record monitoring operation is a compulsory in order to capture records of activities done, any problem encountered, and lesson learned for future project.

The diagram above is taken from the PETRONAS Carigali Sdn Bhd (PCSB) where different oil and gas company have their own uniqueness in the operation, but the basis of the operation would be similar from different organization where the objective is to complete the whole operation safely and the minimize the cost required to maximize the profit gain from the whole operation. One of the objectives from this paper is to utilize the offline activity on the rig which the procedure of the whole operation is crucial in determining whether there is any activity that can be carry out prior to the arriving of the rig at the site. This offline activity would be discuss more in the next subchapter but to show the correlation between the overall operation of the workover and the offline activity itself.

2.2 Overview Partial Plug & Abandonment

Well plug and abandonment is a natural part of the oilfield lifecycle where at the end of the well production, when the hydrocarbon produce shows negative profit to the production, hence the well will be stop producing and be plug and abandon. Even though, the well is still producing, but the amount produce does not give any profit indicator, as the Operating Expenditure (OPEX) is higher compared to net profit gain. There are 2 types of well plug & abandonment which is permanent and partial since the operation at field A have both permanent and partial P&A, in this paper it will focus on the partial P&A only to corelate with workover operation.

2.2.1 Definition

When a well approaches the end of its useful life, it needs to be closed off and left permanently. In order to isolate the reservoir and other fluid-bearing formations, multiple cement plugs are often placed in the wellbore during plug and abandonment (P&A) operations. Well permanent P&A has been a significant concern for a number of years [5]. The requirement must be meet for the wells to be plug and abandon as this will prevent from the hydrocarbon to reach the surface. This activity is very crucial to the environmental impact as if the well is not properly plug then there will be a chance for the hydrocarbon from reservoir to flow to the surface.

Based on the Schlumberger Oilfield glossary, P&A is defined as to get a well ready for permanent closure, usually after production operations have drained the reservoir or when logs show there is not enough hydrocarbon potential to finish the well. Each regulatory body has its own standards for procedures involving plugs. The majority demand that cement plugs be installed and tested in freshwater aquifers, all casing shoes, any exposed hydrocarbon-bearing formations, and possibly a few more locations close to the surface, such as the upper 20 to 50 feet [6 to 15 meters] of the wellbore. Bridge plugs and cement slurries can be used by the well designer to prevent greater density cement from falling into the wellbore.

P&A operations, however, can be quite expensive and time-consuming depending on the well conditions. Furthermore, it is far more expensive to abandon offshore wells than onshore ones [5]. For instance, in the next ten years, it is anticipated that over 2,000 wells in the North Sea will be permanently capped and abandoned. In the next years, decommissioning operations in the North Sea are expected to cost up to £3 billion annually, with over half of those expenses going toward well P&A operations alone.

Operators may be relieved of certain responsibilities if a well is partially plugged, however for the sake of yearly fees or plans, the well may or may not be considered plugged and abandoned [6]. Operators must adhere to all regulations regarding plugging and abandoning wells while partially plugging one, with the exception of those pertaining to surface plugging, casing recovery, oversight of surface plugs, and environmental inspection.

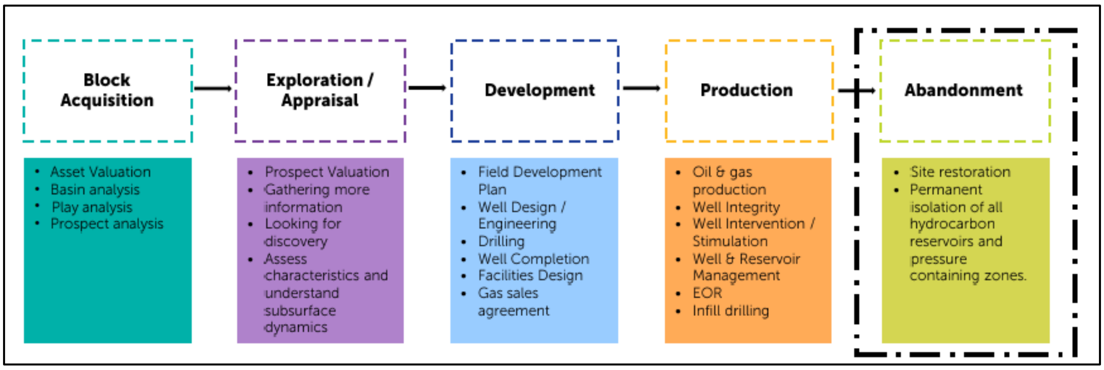

Figure 2.2: Oil and Gas Activity Overview

Based on the figure above, it shows the standard oil and gas lifecycle from the block acquisition to the well abandonment. Partial P&A is at the last stage of the oil and gas cycle which the objective is not limited to the site restoration, permanent or partially isolation of the reservoir and pressure containing zones. As mentioned about the environmental affect, this operation also to give assurance to the safety of the personnel at the platform, where partial P&A is usually where the well have future planning to be used.

Partial P&A is included at the last stage of the E&P lifecycle even though there will be future use of the well, but the scope of the operation is still under P&A

team as it involves the barrier requirements and refer to the whole P&A operation. As mentioned in the above paragraph, prior to commencement of the P&A operation, the contractor or the operator must have a SWAP an official document provides by the PETRONAS [7]. There are 3 types of SWAP based on the objective or work scope of the P&A accordingly which are SWAP-1, SWAP-2A and SWAP 2-B. To summarize the difference between these 3 types of SWAP, it shows at the diagram.

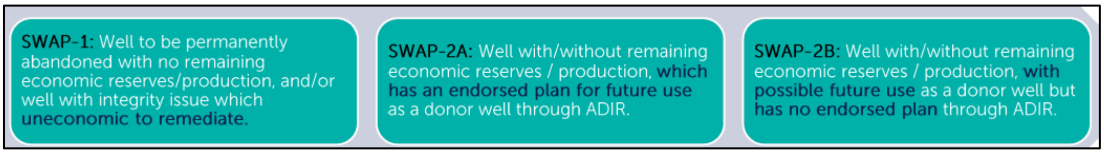

Figure 2.3: Different Type of SWAP based on PPGUA

Based on the figure above, it shows that for permanent P&A it will fall under SWAP-1 while for partial P&A it will fall under scope SWAP-2A and SWAP-2B. For this paper which at field A specifically, the operation will refer to the SWAP-2A where there is an endorsed future plan for the well accordingly that will support Kasawari CCS project. The scope that falls under SWAP-2A stated that the well with or without remaining economic reserve or production, which has an endorsed plan for future use as a donor well through Asset Development Integrated Review (ADIR). The decision making for the future planning of the well either to fully abandon or utilise the wellbore as a donor will such as for sidetrack or convert into injector well, must go through project maturation through ADIR [7].

As stated in Volume 7, Sections 8 and 9, that is isolated with permanent barriers. In compliance with Volume 7, Section 9, barrier placement must be confirmed and tested. If tubing is not in place and barrier verification is not possible, tubing must be cut and retrieved. Either the suspension cap or the leak-tight Christmas tree now in place secures it. Correcting well integrity issues is also included in the partial P&A scope [7]. The remaining P&A tasks, such as cutting and pulling casing string and installing surface plugs, will be finished during full well abandonment.

Furthermore, maintaining well integrity after abandonment is a crucial component of P&A. Since P&A operations regulations were ambiguous and insufficient in the past, not much focus was placed on making sure that wells were properly plugged [5]. This is why a number of wells that are old, blocked, and abandoned are leaking. The 2010 Macondo disaster and the catastrophic oil spill that followed, along with advancements in technology and regulatory policies, have led to a number of notable changes in the industry's perspective on P&A in recent years. P&A operations increasingly prioritize cost-effectiveness over environmental concerns like stopping leaks.

2.2.2 Procedure

The whole operation for partial P&A would almost be similar with permanent P&A as both involved placing permanent barrier that have been tested and verified inside the wellbore whereas according to the PPGUA 4.1 Vol 7 Section 8 there shall be 2 well barrier available during all well activities and operation including suspended or abandoned wells to prevent uncontrolled outflow from the borehole or well to the external environment [2]. This may be different based on the operator and region and since operation at Field A located at Sarawak water region hence all the operation must comply the requirement from MPM and PPGUA.

One of the difference for the permanent and partial P&A is the existing of surface setting plug where only permanent P&A required for the surface of the well to be plug via cement or other permanent well barrier that consider a good barrier which pass the integrity barrier test. The requirement to cut the casing also only applicable for the permanent P&A operation whereas for partial P&A it is not necessary since there is a tendency to use the well again in the future.

In other cases, a well's top section is intended to be derailed in order to reach a different target, while the well's bottom is the sole part that is permanently abandoned. This strategy is economically attractive, especially for offshore platforms when numerous wells are drilled and/or producing from a single platform structure, because the top infrastructure may be reused [8]. The slot recovery procedure is the name given to this process. The well's lower part is the only one that has been permanently abandoned. Side-tracking the well allows access to a new target through the upper segment.

This paper only focuses at Field A, there are 2 wells that undergoes partial P&A which will further convert into injector well that support Kasawari CCS project. The sidetrack activity required the bottom part below the sidetrack point to be abandoned accordingly before the sidetrack operation commence. The partial

P&A come in the picture where to abandon the lower part of the wells is required for the sidetrack activity to be start.

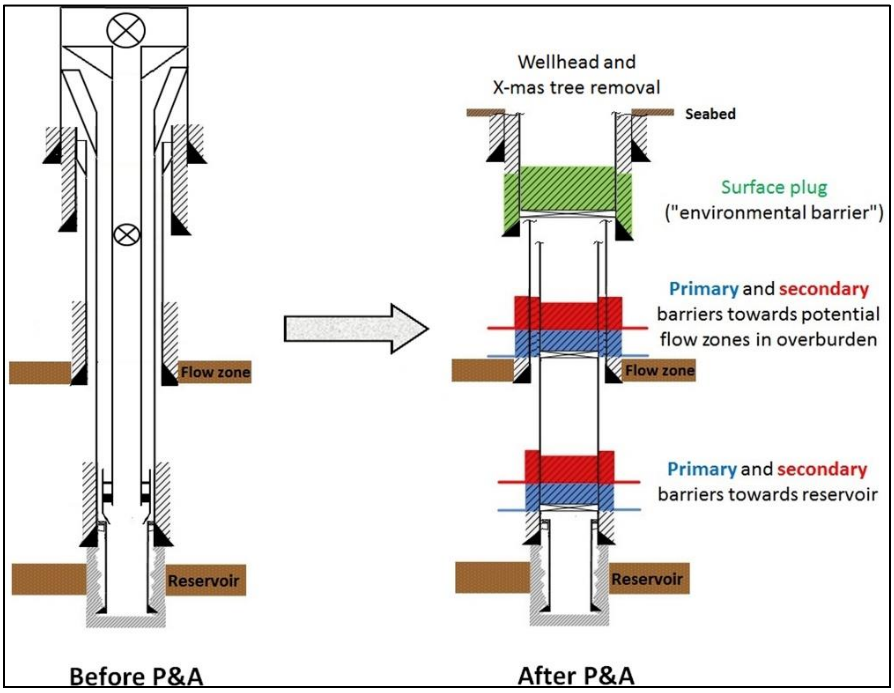

Figure 2.4: Simplified illustration of a typical offshore production well before and after P&A. The colour coding of primary barriers (blue), secondary barriers (red) and surface plug (green) are based on current Norwegian well barrier definitions [8]

Based on the diagram above, it shows the simplified version of typical offshore production well before and after the permanent P&A. This is consider as permanent P&A due to existence of the surface setting plug at the top of the well or known as environmental barrier. For the partial P&A it also needs minimum 2 well barrier where it will highly located at the perforation zone or knowns as caprock restoration method.

Balance cement plug is the most common permanent barrier used in the wellbore during permanent and partial P&A. in order for the BCP to be done, the cement behind the must be evaluate first via CBL and CAST running together inside the hole. If the result shows good cement behind the casing, then BCP operation can be done, this is important to be done as if the cement behind the casing is bad and poor there are tendency for the annulus pressure build up (APB) which will lead to casing collapse.

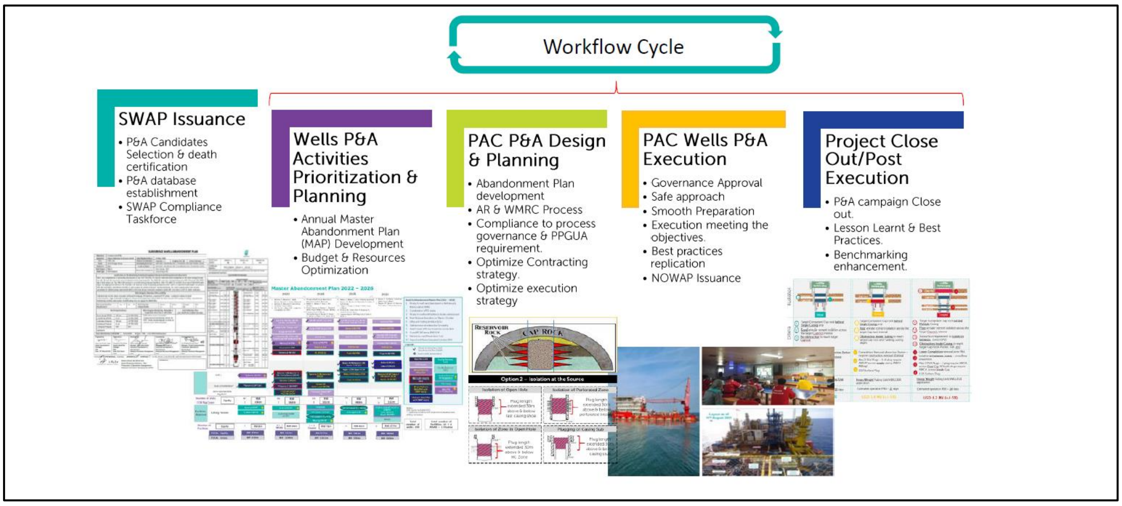

Figure 2.5: Workflow cycle for P&A

Figure above shows the typical workflow cycle from SWAP issuance to the Project Close Out/Post Execution. The party that responsible to give SWAP is MPM where it acts as the owner of the region hence the approval come through this department specifically in PETRONAS. This can be seen from the planning duration to the execution can take up to 2 years from detailed design, schematic diagram of the well and the post execution to capture any lesson learn from the whole operation.

The majority of difficulties stem from the partial abandonment process. It is recommended to partially abandon the slot recovery process [8]. Typically, the platform has many well templates to drill and produce various well configurations. The operator maintains the viability of the supporting infrastructure once the producing reservoir reaches maturity by reclaiming a slot from an underperforming well and drilling a new well to reach a more productive target. This involves side-tracking the well to reach a new destination by using the top segment while permanently abandoning the lower section of the well. Within the Norwegian industry, the process is executed through multiple stages.

2.3 Rig Selection

In this chapter, it discusses one of the crucial element that can give cost reduction for the whole operation which is rig selection. The reason, both workover and partial P&A are discuss in the same paper are the similarity of both operation which in fact at field A, it shares the same campaign, hence both operation are using the same rig. There will be 4 rig that will be compare for this chapter which is Hydraulic Workover Unit (HWU), Jack Up Rig (JUR), Semi Tender Assisted Rig (Semi-TAR) and Drillship. Field A is using Semi-TAR from Sapura, Sapura Alliance hence in this paper there will be a justification to justify the rig selection at Field A.

Every well is unique, and to best serve them, a particular kind of workover rig is typically needed. Furthermore, the intricacy of workover procedures varies; an intervention may take a single day for certain wells, while it may take months for others. Because of this, it might not be able to complete all workover activities in the allotted time frame [9]. As a result, businesses might have to choose which wells to service based on their oil production and the rigs that are available.

In order to reduce costs and decommission platform-based wells, the oil and gas industry developed a number of alternatives to traditional jack-up rigs over the last few decades, including hydraulic workover units, light intervention vessels, modular drilling units, semi-tender rigs, and jack and pulling units [10]. In order to reduce the need of rigs to a larger extent, these rigless decommissioning solutions either anticipated that the rigless package would be put wholly on the platform deck or that it would be supported on a barge or DP equipped supply vessel. Up until the pre-downturn period, when the day rates for traditional jack-up rigs skyrocketed to as high as $150,000, these solutions tended to be appropriate for their intended use and showed promise for cost-effective well abandonment operations.

The production of the well, the workover rig's current location in respect to the demanding well, and the type of service to be performed are some of the criteria that go into deciding which workover rig should be deployed to perform some well maintenance. The goal of the workover rig scheduling problem (WSRP) is to minimize the production loss caused by the wells that are waiting for maintenance services by determining the optimal timetable for the few available workover rigs [11]. The overall cost comprises the time and distance dependent rig expenses (logistic, manufacturing, and activities) as well as the time-dependent revenue losses in the wells that are waiting for the rig [11]. As a result, the itinerary's proper ordering determines the overall cost.

The workover rig scheduling problem (WRSP) is the term used to describe this decision-making process. Because of this issue, wells must undergo workovers—interventions meant to rectify or restore oil flow—during the scheduling horizon. In contrast to conventional scheduling difficulties, these time spans are usually quite long—a few years or several months. This is because of the nature of the tasks that are completed, which usually take several days or months [9]. Oil rigs carry out these interventions, which are only permitted on the wells following a release date determined by the wells' life cycles and production schedules. There is a loss in oil output from wells that need workovers because of the waiting period. This is one of many tools for the rig selection process where via WSRP focus on the detailed and thorough scheduling of the workover operation. A tight schedule may be good and bad where every contingency must always be include in the planning phase or else the plan will be too optimistic hence the actual may vary with plan.

The profitability of the wells could be jeopardized by delays in oil production caused by an undersized fleet of rigs. On the other hand, excessive inactivity and opportunity costs can result from a big fleet. Because of this, rig fleets need to be carefully scheduled and managed in order to guarantee that the rigs will be accessible at the most affordable price and at the appropriate location at the appropriate time [9]. This show a thorough study is a crucial task to be do prior to selecting the rig for any operation specifically for workover and partial P&A activities. There is never exist a best rig for the drilling operation as every rig have their pros and cons that need to be study in term of activity involved, space required for equipment spaced on the rig, and the location since the depth of the well is a major factor for rig selection.

An essential, fundamental measurement technique for performance measurement systems is overall equipment effectiveness (OEE). It has been proposed that OEE could serve as a "benchmark" for gauging process performance [11]. By doing so, the degree of improvement made can be measured by comparing the primary OEE metric with subsequent OEE readings. By lowering the associated losses, the OEE is used to assess the efficacy of total preventive maintenance and enhance it in specific equipment.

Parameter		Typ. Jack Up Rig	Typ. Semi-Tender Rig	Typ. Modular Drilling Unit	Typ. Pulling Unit	Typ. Hydraulic Workover Unit
Hoisting	Drive	Drawworks, Traveling Block	Drawworks, Traveling Block	Rack and Pinion Mast, Traveling Block	Hydraulic Mast, Rig Assist Jack	Casing Jack
	Capacity	> 2,100,000 lbf	> 1,000,000 lbf	800,000 lbf	Mast - 221,000 lbf Rig Assist - 600,000 lbf	460,000 lbf
	HP	> 5,750	> 3,000	1,000	430	600
	Setback	Yes	Yes	No	Yes	No
	Design Speed	1,800 ft/hr	1,400 ft/hr	1,200 ft/hr	1,500 ft/hr	800 ft/hr
Rotation	Drive	Top Drive	Top Drive	Top Drive	Power Swivel Top Drive	Rotary Table
	Capacity	Up to 120,000 lb.ft	Up to 60,000 lb.ft	Up to 60,000 lb.ft	12,000 lb.ft or 21,000 lb.ft	22,000 lb.ft
Setback	Type	Automated Iron Derrickman	Work board in Derrick		Gantry System	
	Capacity	> 2,250,000 lbf RII Triple or Quad Stands	> 750,000 lbf RII Stands 5.5" 19# 19,740ft		160,000 lbf R II 3.5" 13.3# 10,900 ft R III 3.5" 9.2# 17,380 ft	
Sub-Structure	Capacity	> 28,000,000 lbf combined loading	> 4,000,000 lbf combined loading	> 3,200,000 lbf combined loading	Up to 1,000,000 lbf combined loading	Up to 600,000 lbf combined loading
Pumping	Type	4 x Triplex 1600 BHP Pumps	3 x Triplex 1200 BHP Pumps	4 x Triplex 1200 BHP Pumps	2 x Triplex 600 BHP Pumps	2 x Triplex 600 BHP Pumps
	Capacity	>18 bbls/min @7,500 psi	>18 bbls/min @7,500 psi	>18 bbls/min @5,000 psi	11 bbls/min @3,000 psi	11 bbls/min @3,000 psi

Figure 2.6: Comparison of rig in term of varies parameter

Based on the figure above, it shows the simplified comparison between 5 different rig for P&A operation. The comparison parameter for the rig is the hoisting system, rotation system, pumping system, setback, and sub-structure. This is to show how other rigless is a good alternative for cost saving for the operation especially for P&A operation.

How rig selection can affect the optimization of the whole operation for workover and partial P&A activities at Field A is the operating daily rate (ODR) is very expensive hence every second on the rig is very precious. Since this is P&A campaign, the daily cost for semi-TAD rig is around 75 000 USD where different purpose of rig has different rate. The workover operation has saw and grab the opportunity to share the campaign with the P&A team hence the ODR can be optimize in this case. The more difficult the operation, the more equipment needed to ensure the project run as planned. The complexity at Field A is consider a medium complex well where average TD is around 6500 – 7000 ft-MDDF and the deviation is around 40° - 45°.

2.3.1 Hydraulic Workover Unit (HWU)

Hydraulic workover unit commonly known as HWU is the most used rig for workover as it has high capability hence there is low limitation for the workover operation. Variety activities can be done, since its high capability and capacity for pulling operation since workover will definitely involve Pull Out of Hole (POOH) phase to pull the completion tubing from the well to the surface. The cost is slightly lower than the Jack-Up rig make it be one of the best alternative for conventional rig to be used for workover operation in economic reasons.

In essence, a hydraulic workover unit (HWU) is a well servicing system that can run and retrieve jointed pipes and carry out minor well repairs or workovers that would often need the use of a rig and be much more expensive [13]. As the operation at Field A is permanent P&A and workover, hence the use of HWU is a promising rig since its capability to carry out all the pulling tubing and casing, cementing job and set the packer inside the well. The most common factor that will be looking into prior to the rig selection is the capability, space and the cost. Once the objective of the operation has been finalized then all the study will be done to choose and select the best rig that will give benefit to the organization.

The HWU is a more portable and compact machine than a standard workover rig, so that it has less of an impact on the wellsite. However, it is still well than capable of handling any obstacles and replacing defective ESPs. There are a number of significant advantages, such as the avoidance of well disturbance to neighbouring wells, quicker well turnaround times, lower costs, and eventually higher production availability [14]. In order to make room for the rig and its accompanying equipment, the candidate well and any adjacent wells must remove flowlines and instrumentation due to the size and scope of typical workover rigs and well spacing.

A conventional HWU's high degree of accessibility in confined locations, which enables the unit to be constructed in small multiple separate components, is one of its main design benefits. The difficulty was to take advantage of the greater accessibility while also reducing the rig time for a quicker and more effective process, as this can be a very time-consuming task [14]. In order to do this, a specially designed, functional HWU with modular construction bundled into small components that enable quick setup and effective unit deployment was used. This highly accessible HWU can replace the malfunctioning ESP without affecting the instrumentation and production flowline equipment that has already been installed.

Figure 2.7: Different Specification for HWU

Based on the figure above it shows the common specification for the HWU from different operator that provide the rig. Each unit number represents the maximum pulling capacity of the HWU rig in thousand pounds (klbs). The capability of the rig is highly dependent on the pulling capacity hence the relationship between the rig g capability and the cost is proportional. As higher cost needed to accommodate all the necessary equipment for the whole operation to be carry out.

In comparison to a jack-up rig, HWU has a few limitations regarding its operational capabilities. HWU's construction, tripping performance, lifting techniques, and contract administration are only a few of the drawbacks. From a construction perspective, HWU is more vulnerable to weather, making operation suspension more likely. Due to the crane's limited reach, HWU requires more sophisticated lifting operations on particular platforms; as a result, a second crane is required for assistance. Moreover, HWU uses traveling slips for tripping, so the speed is dependent on the cylinder's length. Furthermore, the fact that certain crucial services are not allocated to support the operation puts HWU in a difficult position.

Since operation at Field A involve P&A hence there are phase that required to cut the casing and retrieve the casing from the well. Higher pulling capacity needed for this operation as the weight of the casing would be more than other tubular inside the well.

2.3.2 Jack-Up Rig (JUR)

Jack-Up Rig is widely used for shallow water operation which the leg is capable to spud at the seabed. Shallow water is when the depth of water is approximately lower than 450 ft. One of the great advantage of this JUR compared to HWU is its capability to operate during bad weather, where the anchor system at JUR is much more reliable compared to the HWU.

For many years, jack-up drilling platforms have been utilized in the vicinity of offshore oil and gas resources for work-over, drilling, and exploration purposes. Numerous techniques are employed to maintain control while lowering the elements that impact the Jack-up Rig (JUR) elevating operation [15]. The combination of mobility, the capacity to raise the platform above sea level for a range of water depths, and the ability to operate as a fixed platform, on the other hand, addressed them as valuable in the offshore field throughout the preceding 30 years [16]. A jack-up platform is essentially a portable equipment that may be utilized anywhere in the world with specific maximum water depths, sea states, and different sea bottom conditions.

Figure 2.8: Borr Drilling's 10,500-gt jackup rig Gunnlod

Based on the figure above it shows the 3 legs JUR rig that have been move from 1 location to another location since it does not have any propeller to move it around.

The JUR is a kind of movable platform that has a floatable hull and many detachable legs. It can raise the hull above the sea's surface and typically uses three or four legs. The 3-legs JUR, for example, are triangular barges that are completely furnished during the drilling procedures and consist of three truss legs; other variants are less commonly utilized due to their intricate structure and placement. In addition, JUR got its name since they invented the self-elevating control system, which has eight, six, four, and three movable legs that may be extended beneath or above the hull.

The JUR can drill in waters as deep as 350 feet, according to current labor environment assessments, but for deep water that is, less than 600 feet the total economics and operational efficiency of the deep-water JUR typically make them more advantageous than shallow water semi-submersibles [15]. Because in the notion of jack-up and semi-submersible rigs, the JUR will always be preferred over a semi-submersible rig, providing both are capable of drilling the well. In the oil and gas industry, the cost and economic factor will always consider as crucial factor in design process.

The Hull, the Legs and Spud-can footings, and the Jack-Up apparatus comprised the three primary parts of the JURs. This is the most common part of the JUR and may have different opinion regards to this. These elements are explained below;

1. **The Hull**: The JUR watertight hull houses or supports the systems, personnel, and equipment needed for routine tasks. While the Jack Up is afloat, its hull provides the necessary buoyancy to prevent it from sinking. Furthermore, depending on the various ways that the unit operates, the hull's specs may alter. Most commonly, loads from wind, current, and waves are directed toward the hull [15]. Moreover, a Jack Up unit's freeboard determines how stable it is afloat the most.
2. **The Legs and the Spud-can footings**: When the unit is elevated, steel legs and spud-can footings aid to preserve the hull and offer the necessary stability to withstand lateral forces. The Jack Up can be used in locations

where the soil strength is lower than if the bearing area was less because Spud-can footings are used to increase the soil bearing area [15]. It's also important to comprehend the various characteristics of the legs and the Spud-can footings, as they affect the unit's performance in elevating and floating modes.

3. **The JUR Equipment**: Every JUR unit needs the right equipment to accomplish its objective. This equipment therefore affects the overall rig's hull size and lightship weight. Furthermore, the three main types of equipment used on the rigs are Marine Equipment, Elevating Equipment, and Supporting Equipment. Numerous hydraulic systems and dynamically linked equipment exist, the majority of which are automated and electrical systems [15].

Mentioned above is the 3 main component of the JUR where without one of the component the JUR would be difficult to operate. There are a lot of studies that can be done to improvise the current design of JUR but for this paper it is limited to the cost and capability to operate on the rig only. It will not go deep down into the type of mooring system, anchor system and every equipment on the rig itself. The reason why this rig is favour compared to other rig is because of the economic reason where the ODR for JUR is much lower compared to the drillship and semi-TAR.

Since the JUR was designed mainly for short canals with limited water depth capabilities, the transit schedule and setting up the legs in inclement weather provide the most challenges. The legs of the JUR are supported by its foundation, which also specifies the stiffness characteristics that limit the types of weather the JUR can tolerate. Based on the data from the geotechnical research, soil features such as the lower and upper bounds of the friction angles were identified and examined.

Prior to relocating the JUR to the installation site, the evaluation for the leg penetration was also examined [15]. In relation to the foundation, when preload is applied, the foundation needs to have sufficient resistance to stop the spud-can from sliding and strong enough to stop the spud-cans at the base of the legs from penetrating too deeply into the seabed. Cantilever drilling is usually reserved for units with independent footings, while slot type drilling is frequently utilized for supported footing units.

The buoyant hull of the JUR has multiple movable legs that allow it to be raised above the water's surface. On the other side, the buoyant hull enables the unit to be moved to the proper location together with any attached equipment. The JUR may be moved in two different ways: either by floating on its decks and being towed to the new location by tugs or barges, or by floating in self-floating mode and using either of its propulsion systems in a wet-towing scenario. Even though the dry-towing approach is quicker than the wet-towing approach, the majority of JURs are not self-propelled and must travel slowly in the company of tugboats or big ships.

In this paper since it is related at Field A only and the operating was during monsoon where the weather is rough and bad the tendency to choose JUR is much more likely compared to the HWU. This is due to the capability for the rig to operate at bad weather conditions, but it is also limited since the anchor system for JUR is not dynamic positioning compared to the Drillship and Semi-TAR which have its own propeller for better positioning of the rig.

2.3.3 Semi Tender Assisted Drilling Rig (Semi-TAD)

One form of development drilling, workover, or plug and abandonment rig that is now in use is the tender aided rig same "family" as jack up rig, semi-submersible, or drillship. But it's the only design that can function in shallow water as well as deep water 66ft to 6,562ft. Within the industry, it is acknowledged as one of the most cost-effective and efficient rig types for P&A, work over, or development. They are made up of self-contained drilling rigs and tender vessels, which are support vessels with particular designs. Typically, the tender vessel has a helideck, cranes, power generation facilities, living accommodations for 120–200 workers, and storage facilities for bulk, mud, tubes, spare parts, and consumables.

With a drilling depth of up to 30,000 ft, tender-assist drilling (TAD) rigs can perform plug and abandonment operations, well completion, development drilling, and workovers in waters ranging from 30ft to 6,000ft. The TAD is usually positioned next to a platform. The capacity of the drilling package to self-assemble, the vast storage capacities for fluids and tubing, and the offline capabilities are the key advantages of TAD [17]. It can rig down and proceed to another platform for distinct operations after the drilling is finished. For the client, this means sustainability and efficiency. When the drilling package is in operation, the TAD supplies electricity and other necessary services to support the well operations while remaining stationary on an eight-point mooring system.

Tender Assist Drilling (TAD) rigs come in two varieties: semi-tender rigs and tender rigs. While they both have the same gear, the latter can function in rougher environments at even deeper depths. The TAD is usually positioned adjacent to the platform, and its drilling package is raised onto it. The TAD provides power and other operations-supporting services while remaining stationary while the drilling package is in operation [18]. Additional advantages and benefits consist of:

1. Drilling development wells, the capacity to self-raise, remove its own drilling package, and then rig-up on the same package on another platform leads to enhanced sustainability and efficiency.
2. There was a decrease in operating expenditure (OPEX) and capital expenditures (CAPEX) over the course of the fields due to;
    - Several wells drilled from a single location, cutting down on well-to-well time and enhancing personnel and logistical planning synergies.
    - Significantly reduced well durations that lead to better results in dry tree operations, batch drilling, and simultaneous operations (SIMOP)
    - Enhanced maintenance schedules
    - Drilling equipment is used more frequently because of its mobility.

Tender assistance drilling has advanced to a new degree with the introduction of the semisubmersible tender assist drilling (TAD) unit. Drilling contractors and operators have successfully converted semisubmersible mobile offshore drilling units (MODUs) to function as TAD units on a temporary basis since the mid-1980s. The semisubmersible TAD idea, which began with the Seahawk MODU conversion in 1993, has developed into a dependable and effective development alternative for depths up to ultra-deepwater, surpassing the advantages of its mono-hull predecessors (ships and barges) by offering the following [19]:

1. Improved motion characteristics are especially crucial when transporting relatively big weights and while rigging up and down the drilling equipment set (DES) on the platform.

2. Increased space efficiency as a result of the physical layout, which gives cranes a shared area to store and arrange consumables (double handling is frequently needed for mono-hulls).
3. Self-erection in a single posture while anchored. Self-erecting monohulls frequently have to moor beam to the platform before moving to the bow position.
4. Elevation increases facilitate crane access to the towering platform, which is more than 142 feet tall.
5. increased dependability in station keeping and mooring. Monohulls adjacent to platforms are vulnerable to beam loading and mooring system failure since they are unable to weathervane.
6. A safer and easier way to load and unload workboats.
7. Reduce Non-Productive Time (NPT) due to Wait on Weather (WOW)

It shows how the TAR has given a numerous numbers of the advantages and benefits compare to the other rig, which the reason, the semi-TAR rig become the favourite rig compared to the other rig. Since there is limitation for the Jack Up Rig and HWU to operate during monsoon, this semi-TAR seems to become the game changer since it can be operate to mild kind of weather which ultimately can reduce the NPT hence maximize the production time. The operation at Field A also have use Semi TAR which is Sapura Alliance since the operation will be at the end of year in Malaysia region where it is during monsoon season.

Figure 2.9: Sapura Alliance Semi TADR

Based on the figure above, it shows one of the example of Semi-TAR rig which is Sapura Alliance which this rig has been select and use for the workover and P&A operation at Field A. Even though the cost is higher compared to the HWU and JUR but the other benefit from this rig makes it more promising and give more cost saving for the whole operation.

2.3.4 Drillship

Lastly, the rig that will be compare in this paper is drillship which widely known for its capability to drill a well at deep water operation. It is suitable to be use for workover and P&A operation, but the bigger question is, is it economically good to use drillship for operation workover and P&A since the ODR for drillship is the most expensive compared to the other rig.

A marine vessel that has been converted to drill gas and oil wells is called a drillship. drillships and tankers or cargo vessels may have similar exteriors, but there are a few key distinctions. drillships come with a moon pool and drilling derrick. drillships also have an extensive mooring or positioning apparatus, along with a helipad for personnel transportation and supply pickup. Drillships operate in water depths ranging from 2,000 to more than 10,000 feet (610 to 3,048 meters), mostly in deep and ultra-deep waters. Riser pipe, a rather flexible pipe that runs from the top of the subsea well to the bottom of the drillship, is used to connect the drilling equipment to the well equipment below once it has been passed through the moon pool of the ship.

A drillship is a transportable offshore drilling rig that is designed to serve as a platform for a monohull, catamaran, triple-hull, or barge ship. Drilling a well starts when the drillship reaches the well spot and aligns itself using the mooring system or dynamic positioning system. When the ship is operating, it is afloat. The drillship will experience heaving, swaying on both sides, floating on the surface, and other effects from the wind and waves. Therefore, in order to ensure that the drillship is displaced within the permitted limits while drilling a well, a variety of procedures are required, including a drilling string heave compensation system, swing angle reduction device, dynamic positioning, and more.

Drillships are easily mobile, setting them apart from conventional offshore drilling units. Drillships are able to move independently from well to well and location to location, but semisubmersible rigs are dependent on an external transport vessel to move them from one area to another. Semisubmersible rigs can also drill in deep waters. Drillships can drill in deep and ultra-deep waters, but one drawback is that they are easily disturbed by wind, waves, and currents. Because the drillship is attached to equipment thousands of feet below the surface of the ocean, this becomes particularly problematic when the vessel is really drilling.

The drillship has several advantages, including excellent mobility, a fast rate of self-propulsion, and the capacity to manage a variety of varied loads. The impact of fluctuating loads (drill pipes, casting pipes, drilling fluids, raw materials, cement, fuel oil, water, and so forth) on draft is negligible because of the wide waterline area. It can support itself well, has a big working depth, and a lot of storage space. 200 to 300 meters is the maximum working depth that can be reached when anchored with an anchor. Its work depth can be as deep as 6000 meters if it employs a computer-controlled thruster in a dynamic positioning system.

The drillship also has some shortcomings, including poor stability, particularly when moored with the anchor; strong wind and wave influence, which can reduce drilling efficiency; a small deck area for decks; and high cost (especially if the drillship is equipped with a dynamic positioning system). All things considered, the drillship is well-suited for drilling in deep water areas due to its exceptional advantages. It is turning into a more and more crucial instrument for finding oil in deep water. China stopped developing No. 1 of Exploration after completing its construction in 1974. It's time to adapt to the new gadgets.

2.4 Offline Activity

The workover program is a systematic, step-by-step process that must be adhered to when carrying out the workover operation. This workover operation includes the primary workover stage. The rig is moved to the oil well's site, and numerous procedures need to be followed in order to have the oil well producing normally again. The equipment such as ESP is installed using methods like rig up (R/U), rig down (R/D), and run in hole (RIH) and pull out of hole (POH). Operating personnel must receive all the information from the program they need to safely accomplish the needed goals at the lowest possible cost and resource consumption.

Offline activity is defined as operationalizing an event concurrently with online activity at rig floor, without compromising outcome of online activity and safety of personnel. Offline activities reduce flat time directly. Flat time refers to time that passes with little to no notable occurrences or changes. It is the same as ordinary time; minutes, hours, and seconds pass with nothing remarkable or spectacular happening. Previously the specific activity was performed at rotary table with assistance of the Top Drive System (TDS) and the majority of rig equipment. Recently, technology development and rig capability have enabled certain activities to be performed offline.

Prior to performing offline activity, thorough risk assessment and feasibility study need to be conducted with relevant personnel. By this the operator could identify inherent risk and prepare solution to reduce risk level to As Low As Reasonably Practical (ALARP). Rig design and capability plays major role in delivering offline operation. Especially for deepwater operations, drillships and semi-submersible which are equipped with double derrick. Basically, a derrick is a hoisting apparatus that consists of at least one guyed mast, similar to a gin pole, that may be adjusted to articulate over a load. Increasing the number of derrick will definitely increase the efficiency of the operation but the limitation is it will require bigger space to accommodate the derrick at the rig.

In the deepwater Direct Vertical Access (DVA) environment, rigs deployed on platforms are usually used for abandonment and workover operations. Nevertheless, there is a substantial amount of work associated with rig workover operations, such as installing cement plugs, cutting tubing, circulating workover fluid, and so forth, which can be completed offline in order to reduce rig days, expenses, worker exposure, and other factors [20]. Assuming this identified rig would not otherwise be idle, offline in this context will be defined as the time associated with operations that can be completed without allocating critical path rig time to abandonment scope, hence saving time and money.

The example of the offline activity are offline R/B casing, offline cementing operation, offline Xmas Tree, Critical Device Function Test (CDFT), offline slickline and Wireline Operation. The offline activity that has been carry out at Field A is cut the tubing via wireline prior to the arrival of the rig at the well slot.

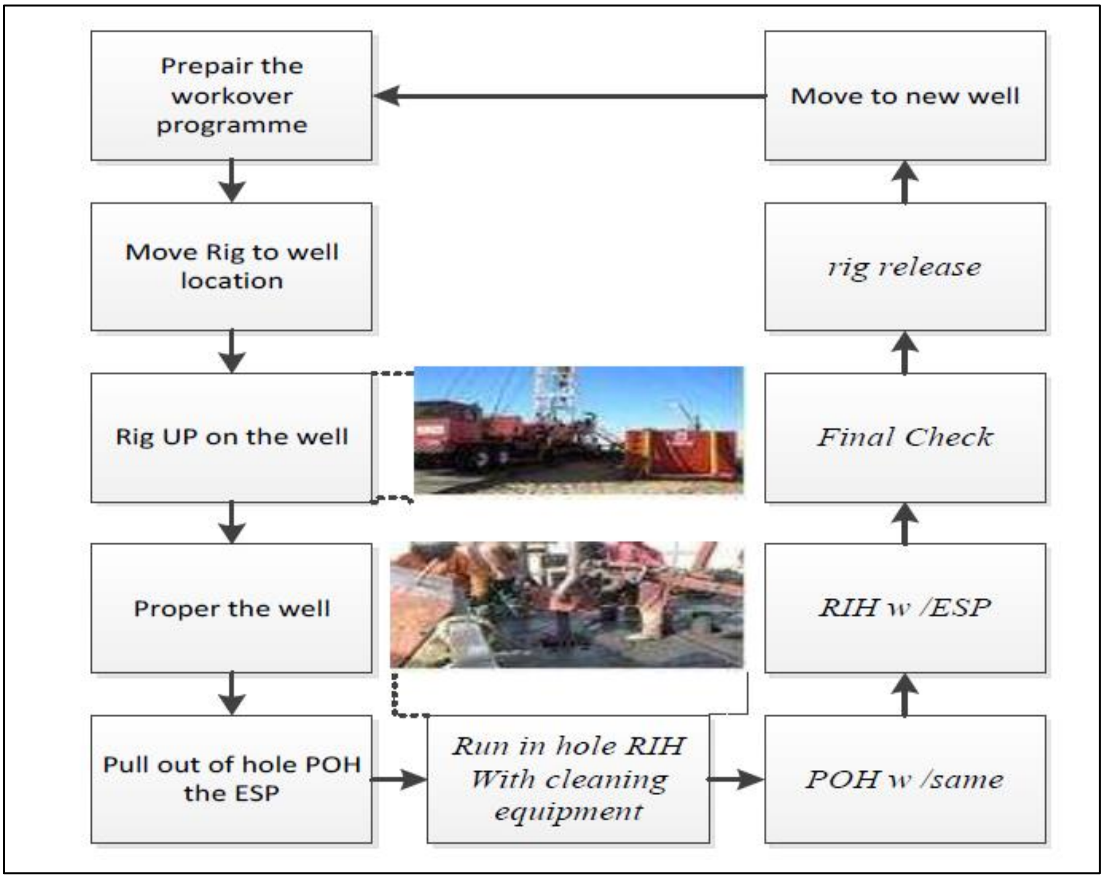

Figure 2.10: The main stages of Workover Operation [21]

Based on the figure above, it shows the typical of workover program from move to new well to the final check and skid the rig to another well. It involves preparing the workover program which in PETRONAS is called Notice of Workover Program (NOWOP) which the engineer will prepare it and the operator will refer at site. This to ensure a clear communication between the engineer at town and the operator at site. As stated by the C.Hosli any offline activity that can be done can help greatly to reduce the rig time which ultimately will allow the operation to save cost.

2.4.1 Cutting Tubing

Workover operation will always required to POOH the completion tubing, since the packer already set hence there is no other choice other than to cut the tubing above the packer. When doing any operation that involves cutting the tubing, tubing cutoff is crucial. Chemical or explosive cutters are used in the most popular pipe cutting techniques.

Chemical or explosive cutters are used in the most popular pipe cutting techniques. The same explosive technology employed in perforating charges is also applied to explosive cutters. However, rather than being formed in a cylindrical cone, the explosive and liner are organized in a wedge so that the pipe will be severed by the explosive front of the device pushing out on all sides. While the method works well most of the time, it leaves the outside of the pipe with a flare that is frequently challenging to wash over when performing pipe recovery operations. This flare has mostly decreased to a manageable level because to more recent explosive cutters.

One of the most used techniques for cutting off pipes, particularly for tubing, is chemical cutting. The cutting fluid reacts really fast and produces a lot of heat. It is sprayed all around the cutoff tool at the tube walls using a nozzle assembly. A strong reaction takes place when the fluid makes contact with the steel wall, causing the pipe to split smoothly without producing an outward flare. Chemical cutters have the ability to create extremely smooth cuts, but their effectiveness is highly dependent on the orientation, even coverage, and contact of the cutting chemical with the steel pipe. The following circumstances have the potential to completely thwart or impede the chemical cut on that pipe's side, necessitating tugging operations to finally separate the pipe:

- Thick-walled pipe
- Greater alloy
- Enhanced depth
- Cracks in the pipeline
- Scale
- Paraffin
- Polypropylene Liner
- Inaccurate perforation gun size

Continuous or segmented radial explosive cutters create an outward-facing pressure wave that typically results in a flare in the steel at the cut site. The intensity of this flare may make it difficult to retrieve the pipe or to wash over the trapped area. Before running the wash pipe, a mill is frequently run to dress off the upward-looking connection. Pipe can be successfully severed with mechanical cutters based on mill design in jointed and coiled tubing applications. Despite being far slower than chemical or explosive cutters, these cutters can still be operated with standard machinery. The pipes made of softer, lower alloy with narrower walls work better with the mechanical cutters. It is more challenging to cut thick and high alloy pipes with a mechanical cutter.

Recently reintroduced to the market, abrasive cutters are capable of quickly cutting through nearly any kind of pipe at any depth. These cutters employ the following kind of particulate, glass beads, sand, and calcium carbonate. The steel is worn down by the abrasion caused by the particle that is forced into a revolving nozzle. If the cutter can remain in one spot for the duration of the cutting process, it can even be used to cut through drillpipes with thick walls. Abrasive cutters make extremely quick cuts at the surface, but when they are used downhole, backpressure causes the cutting process to slow down. However, as pipe cutting tools, these cutters are starting to be used extensively.

The cutting system necessary for a particular application depends on the well depth, temperature, and size of the tubing and alloy grade and weight of the tubing. However, the most important factor is any restriction above the cut point and the ability to pull tension on the pipe. Requirements for cutting tubing include knowledge of the specific design of the well and any restrictions above the point to be cut.

2.4.2 Installing Tubing Plug

Different types of service tools are essential for both wellbore completions and isolations. Although it's simple to mistake one for the other since the function of both equipment looks similar, hence a thorough and right decision must be make in order to carry out the task effectively and fit the purpose of the activity. In this section it will differentiate between tubing plug, bridge plugs and cement retainers.

Tubing plug is installed inside the tubing to isolate the lower part of the well. This is to prevent any hydrocarbon to flow from the reservoir to the surface since the well is yet to be kill yet. The safety will always be a priority hence by set the tubing plug inside the completion tubing above the perforation zone will give assurance that the hydrocarbon will not flowing to the surface. Once the above part of the well have been secured, which the part above the production tubing, tubing cut can be done since there are no more hydrocarbon in the tubing after all the pressure test had been carry out.

Schlumberger or called Slb had developed a tubing plug called ‘Pumpout Plug’ which function is to set a packer and supply a tubing stopper without requiring well intervention, create a temporary bridge in the tubing string. The stopper, which is made out of a ball and seat, lets the tubing fill as it runs. The operator can drop the ball off the surface or run it in situ. Once the packer is in place, the plug is sheared by increased tube pressure, which causes the ball and seat to fall to the well's bottom. With certain plugs, the ball is pushed through the enlarged seat and descends to the bottom when the seat slides downward and spreads out into a recess. Either way, a complete tubing ID is obtained.

The other tubing plug that has been developed by Slb is called ‘Tubing Shear Plugs’ which able to maintain pressure from below so that the shear screws are not strained. The plug sinks to the bottom after shearing, leaving the tubing bore completely exposed. They work best in snubbing-type operations because of their solid core. The application of the tubing plug is not limited to the isolate the lower zone only, but it also can be used for;

- Barrier against collisions during drilling operations
- Isolation of the wellhead
- Water shut-off zone isolation
- Zonal separation to avoid mingling or cross-flow
- Downhole suffocation: restricting undesired or excessive gas output
- Testing of tube and packer settings during workovers and completions
- Testing for tubing integrity
- Project Abandonment

In order to provide isolation from the annulus above and allow treatments to be performed to a lower interval, cement retainers are isolation tools that are placed into the casing or liner. In cement squeeze or related restorative procedures, cement retainers are usually utilized. To engage in the retainer during operation, a stinger which is a specifically designed probe is fastened to the bottom of the tubing string. The valve assembly separates the wellbore beneath the cement retainer once the stinger is removed.

Wellbore abandonment and casing repair are two applications of cement retainers in the oil and gas sector. Cement retainers are used in wellbore abandonment to isolate above the cement retainer and squeeze cement into a lower zone. This stops additional hydrocarbon migration into the wellbore by enabling cement to be sighted straight into the zone and squeezed to guarantee a suitable seal. By isolating the above wellbore and enabling cement to be placed directly into the casing that needs repair, cement retainers are used in casing repair to fix leaks, holes, or breaks into the casing. It retains the cement in this place until it has solidified and completed a seal. Conventional drilling procedures can simply remove the cement retainer and any remaining cement in the wellbore.

Whenever sealing a lower zone from a higher zone or totally isolating the wellbore from the surface equipment, the drilling bridge plug is utilized for zonal isolation. Bridge plugs can be placed by operators in a number of ways, including wireline, hydraulic, hydro-mechanical, and fully mechanical. Three types of bridge plugs are available to operators: fully mechanical, hydro-mechanical, and wireline sets. Combining the plug with a packer is one of the greatest ways to guarantee accurate and ideal settings.

Cement retainers and bridge plugs differ primarily in that they are designed to meet the needs of the application. A bridge plug is installed either permanently or temporarily to isolate the top and lower zones of the wellbore, whilst a cement retainer helps with cleanup and squeezing operations. The fact that retainers let operators open and close a valve to perform squeeze operations below them is another obvious distinction. Complete access to the wellbore or below them is blocked by bridge plugs.

2.5 Tools and Equipment Selection

Tool selection will always be a crucial component for the whole operation in E&P as it will determine whether the operation can run as plan or not. A right tool selection will increase the efficiency of the operation as it will reduce the NPT hence the percentage of productive time of the whole operation will be higher.

In this regard, the oil and gas sector, which plays a significant role in the production of power globally, has changed in two significant ways even though there is still a need for these resources everywhere. The first is the substantial amount of "easy oil" that has already been used. As a result, upstream oil and gas companies will have to make investments in increasingly sophisticated technologies when it gets harder to reach exploration sites [22]. Second, O&G companies now have different standards and expectations when it comes to safety, human welfare, and environmental management as a result of catastrophic events like the Deepwater Horizon oil leak. In order to ensure safer activities, new technologies are essential. In fact, the success or failure of a business operation greatly depends on its equipment.

Companies frequently have to choose one or more projects from a portfolio of choices due to financial and legal restrictions. Therefore, consideration must be given to the analysis of pertinent criteria in order to evaluate and aggregate them effectively, particularly in situations where data is few. Usually, knowledge is scarce, especially in the early phases of project development, and historical and performance data are inadequate or imprecise. Historically, the main causes of the poor success rates have been a number of unknown concerns, including technical failure risks and commercial/market risks [22].

In order to ensure consumer pleasure while choosing new equipment, businesses must become extremely perceptive and conduct in-depth assessments. The decision to purchase oversized equipment might affect the business's revenue. On the other hand, inadequately scaled machinery is unable to meet the quality and capabilities requirements of consumers. Although choosing the right equipment is crucial to designing a flexible and efficient production system, there aren't many publications on the topic.

2.5.1 Packer

Packer is a sealing or isolation device that isolates and contains produced fluids and pressures within the tubing string. It is a well barrier element, usually part of the well's primary well barrier, protecting the casing and creating an A-annulus between tubing and production casing.

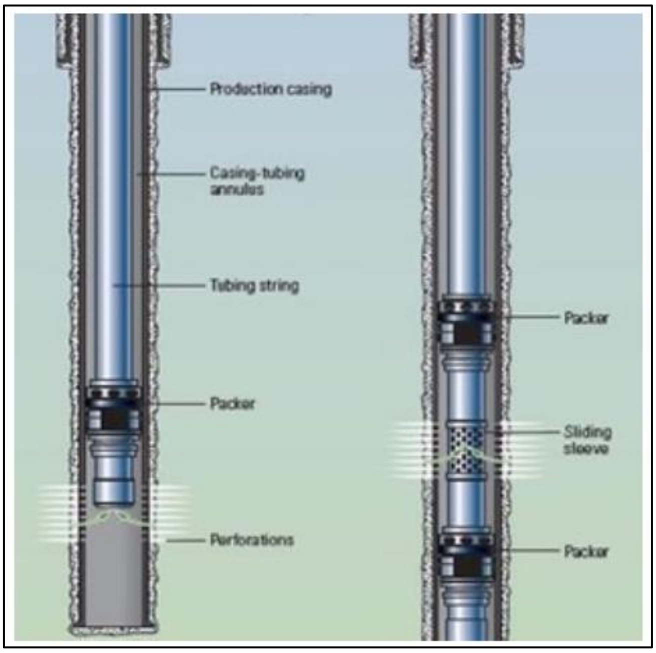

Figure 2.11: Production Packer that have been set

Based on the figure above, it shows the example of the packer that have been set above the perforation zone. This packer has been widely used for the production team where before they perforate the reservoir, the annulus must be seal first so that the whole hydrocarbon will not flow through the anulus but through the completion tubing only. There are a lot of packer function such as;

- Annulus Isolation
- Protect casing from bursting under conditions of high production or injection pressures
- Protect casing from corrosive fluids
- Downhole formation control
- Zonal isolation between productive zones
- Artificial lift
- Down hole anchor for tubing

As more rigorous completion conditions drive more crucial product selection procedures, the long-standing ambiguity around performance ratings for production packers remains a matter of concern. Up until now, a quality selection process has not been supported by inconsistent manufacturer testing methodology and design validation procedures. Completion engineers have relied on the manufacturer's technical know-how and good intentions as they lack a deep comprehension of the subtleties of packer performance characteristics under different load scenarios.

Packer is discuss in this paper since the workover and P&A team would always need to retrieve the packer as the requirement of the activity to POOH the completion tubing. Hence the selection of the packer from the completion team would surely give impact to the next or future activity. In common, the workover needs to retrieve the packer but if the packer used in the downhole is permanent packer hence the only way to retrieve the packer is by mill the packer, then need to fish the packer out of the hole. Milling is not a simple activity since there is the tendency for the tools to stuck in the hole or the mill to tear without be able to mill the packer.

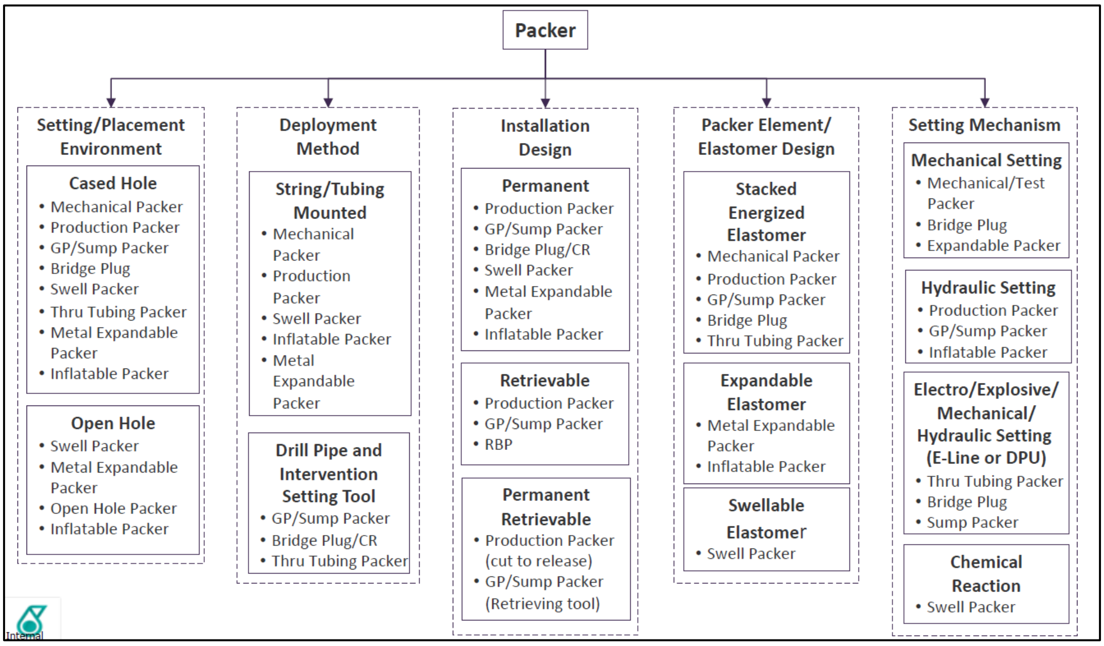

Figure 2.12: Packer Overview

Based on the figure above it shows the overview of the packer. From the setting mechanism, deployment method, installation design and the packer element which the elastomer design. In the result chapter shows 1 advanced technology of packer.

2.5.2 Overshot

The most common equipment used for renovating oil and gas wells is a fishing bit used for drilling. Drilling fishing tool types and specifications are numerous. There are five categories into which the falling objects in the well can be classified: spear tools, overshot tools, junk basket, hook fishing tools, and cutting tools. In this section it will discuss on only 1 of the fishing tools which is overshot.

To recover dropped items from the borehole, a specialized fishing drilling instrument is called a fishing tool. The drill rig operator will run into unforeseen circumstances at any point in the operation, such falling drill string, stuck pipe, missing drill bit, etc. The instruments used to remove the equipment are referred to as "fishing tools," and the equipment that falls into the well is referred to as "trash" or "fish." Using "fishing tools" to recover outdated wellbore equipment, such packers, liners, tubing, or any debris stuck in the well, may be necessary at times. Drilling activities cannot proceed until the fishing drilling tools are recovered from the borehole.

An overshot is a fishing or downhole tool for engaging on a tube's or tool's exterior during fishing operations. The fish is grasped by a grapple or comparable slip mechanism on the overshot, enabling the application of tensile tension and jarring action [23]. A release mechanism inside the overshot enables the overshot to be disengaged and retrieved in the event that the fish cannot be removed. It is widely used in the industry since there is always a high chance for the creation of fish in the well. Fish basically any unwanted tool or equipment that is located inside the well. There is a fish that can be left inside the well and some fish that need to be fish hence overshoot, spear or any fishing tools are required to retrieve the fish.

Based on the IADC Drilling Manual 12th Edition, overshot is a fishing device that is dropped over the exterior wall of a pipe or sucker rods that have become lost or lodged in the wellbore and are fastened to tubing or drill pipe. A friction device that grabs the pipe tightly in the overshot and allows the fish to be drawn out of the hole. This gear is often either a spiral grapple or a basket.

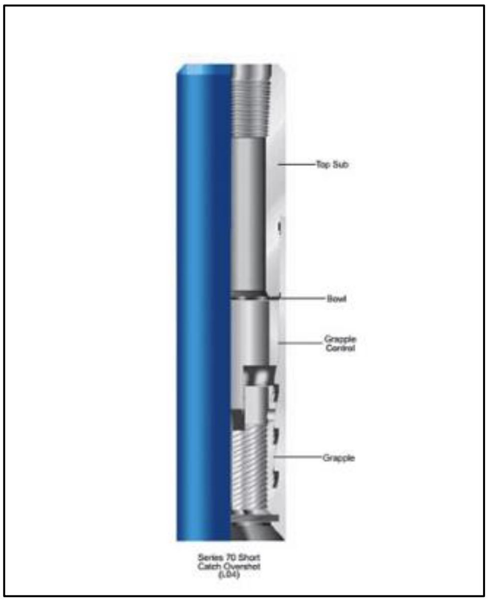

Figure 2.13: DYLT-T Type Series 70 Short Catch Overshot

Based on the figure above, it shows one of the example of fishing tools which is overshot from Saigo Group. An external fishing tool called DYLT-T type Series 70 Short Catch Overshot as shown in the figure above is used to retrieve tubular fish whose tops are too short to be engaged with other overshot [24]. It can catch fish like tubing and casing coupler, drill pipe body, drill pipe junction, and upset portion. This short catch overshot has a wide catch range and is dependable.

In brief on how the overshot works is when the fish is engaged during the fishing operation, the overshot tool's grapple will extend as the operator rotate and lower it, allowing the fish to be swallowed. The fish is now engaged when the operator pull the line, causing the grapple to make contact with the taper inside the bowl. Bulldog, Kelo socket, TMF, Series 150 Bowen, Series 10 sucker rod, Series 20 Bowen, Series 70 Bowen, and other designs are available on the market. In addition, there are numerous accessories that might utilize based on the circumstances.

Overshot and spears, run with grapples sized for the specific outer or interior diameters of the fish, are the most often used fishing tools. The main distinction is that the spear enters the fish while the overshot exits it. The grapple bites into the fish's surface when the overshot or spear engages the wicker profile. The grapple bites into the fish more forcefully the harder the fish is pulled.

2.5.3 Milling Tools

Milling is the process of cutting and removing material from instruments or equipment inside the wellbore using a mill or other comparable downhole instrument. An adequate selection of milling tools, fluids, and procedures is necessary for successful milling operations. The fish materials and wellbore conditions must be suitable with the mills or comparable cutting instruments. The milled material in the wellbore should be able to be removed by the circulated fluids. Lastly, the methods used have to be suitable for the expected circumstances and the expected amount of time needed to accomplish the operation's goals.

Mill cutting surfaces are made of diamond, tungsten carbide, or a mixture of the two. The most common substance is tungsten carbide. It is believed that tungsten carbide is less brittle than diamonds. Moreover, a welder's torch can be used to sweat tungsten carbide particles onto a mill on the rig floor [25]. Mills can be made to cut in any combination of the following: solely on the bottom, inside, outside, or in any combination. For instance, if one wanted to mill a packer's slip without destroying the casing, they would select a mill that had tungsten carbide inside and, on the bottom, but not on the exterior of its cutting surfaces.

A mill's configuration describes its form. In order to remove a tool joint from a drillpipe, for instance, the mill would be set up with blades long enough to cut the tool joint's outside diameter and a stinger in the middle to steady and guide the mill. A mill could be fastened to the end of the stinger to remove and chop things, set cement or mud, or both [25]. The bottoms of mills are concave and convex. Some are solid donuts, while some feature blades. The size of the tungsten carbide determines the size of the filings and has a significant impact on milling speed. Large tungsten carbide particles may be more appropriate for milling a liner since they can cut larger filings.

The process of removing steel is called milling. When drilling oil and gas wells following fishing operation trials, this kind of grinding might be required in several situations. In addition, the steel barrier in the wellbore will be removed, allowing the drilling to proceed to the well target. The operation milling is not limited to fishing activity but is have been used widely such as [26];

- Removal of tools that were previously placed in the well; such as permanent packer, cement shoes, port collars, packer types, and bridge plugs.
- Well sidetrack from the casing by operate or create a window in the casing then using the whipstock.
- Disposal of the left parts of the drill string; such as collar, drill pipe, drilling stabilizers, drilling subs, and stabilizer blades.
- Milling of drilling tools or other junk in the oil and gas wells; such as drilling bits, hand wrenches, clamps, etc.
- Perform a hole through the collapsed pipe.
- Cut casing liners tops and broken pipes.
- Release special tools such as packer slips

Table 2.1: Recommended ROP and weight for different types of mill [26]

Type	RPM	Weight (1000 lbs)	Remarks
Junk Mill	60 - 140	0-30	Spud mill from time to time
Pilot Mill	60 - 140	0-30	Vary weight to find the best ROP
Taper Mill	60 - 140	0-30	Start with light weight and low RPM
Flat Mill	60 - 140	0-30	Start mill above fish
Rotary Mill	60 - 140	0-30	Pick up from time to time. Check overpull and torque. Do no spud unless necessary

Based on the table above it shows how they are vary type of mills where every mill has its own advantages and disadvantages. There are a lot of factor that affect the success rate of the milling operation which type of mill is one of it. The operator which chooses the right type of mill for the right operation will ensure high success rate of the whole milling operation.

Table 2.2: Expected milling rate for different material of fish and mill [26]

Material	Junk Mill (ft/hr)	Pilot Mill (ft/hr)	Flat Mill (ft/hr)	Washover Shoe (ft/hr)
Drillpipe	2.0-6.0	2.0-4.0	-	6.0
Drill Collars	1.0-2.0	1.0-2.0	-	4.0-10.0
-Packers	4.0	-	2.0-3.0	-
Bit Cones	2.0-4.0	-	-	-
General Junk	3.0-5.0	-	2.0-4.0	-
Washover pipe	2.0-4.0	4.0-10.0	-	-
Casing	2.0-4.0	4.0-10.0	-	-

Based on the table above, it shows the different milling rate for different fish and mill used for the milling operation. This data is based on previous historical data where currently as the technology advanced, the rate might be much faster. There are several factor that affect the milling rate which is the type and stability of fish which the fish that is have complex structure require longer time to be mill. The weight and speed of mill which heavier the mill the milling rate will increase too.

One of the main reasons milling is the last resort after all the fishing tools have been used to fish is due to the wellbore clean out. The swarf from the tools that have been mill must be flow out to the surface or else it will sedimented at the lower part of the well which ultimately will cause stuck pipe to occur. Fishing operation will retrieve the fish without the need of mill the tools and create swarf. The swarf will also damage the rubber or polymer property at the BOP which will jeopardize the integrity of well barrier. Hence the correct and right mill must be select prior to the milling operation which the objective should be able to achieve and avoid any other problems such as stuck pipe.

CHAPTER 3: METHODOLOGY

3.1 Overview

The project is solely on the research purpose and the lesson learn that can be capture at the field A for workover and partial P&A activities. This lesson learnt is always a benefit thing especially in PCSB that the whole project management team need to look into during planning and execution phase of any project to ensure there are no repetition of the same mistake and early mitigate can be done for the future project. In this paper, the methodology that be done are literature review, synthesis and analysis.

Based on the objective of this paper which to find any optimization in term of planning, design and operation of the project at Field A based on 3 main components which are rig selection, utilize of offline activities and tools and equipment selection. Various article, magazine, books and report had been refer to throughout the whole process of this project that have been carry out. In terms of rig selection, there are 4 type of rig that have been compare which is hydraulic workover unit (HWU), jack-up rig (JUR), semi – tender assisted rig (semi-TAD) and drillship which the comparison in term of capability, limitation and ODR.

The second objective which is to determine and maximize the offline activity that can be done prior to rig up hence the research that have been done is the operation itself and how the offline activity can reduce the rig time which ultimately reduce the whole cost for the operation. Lastly, the third objective is to propose and justify any new technology for tools selection in the operation will be discuss only 3 tools at the surface only which is packer, overshot and mill.

3.2 Project Flowchart

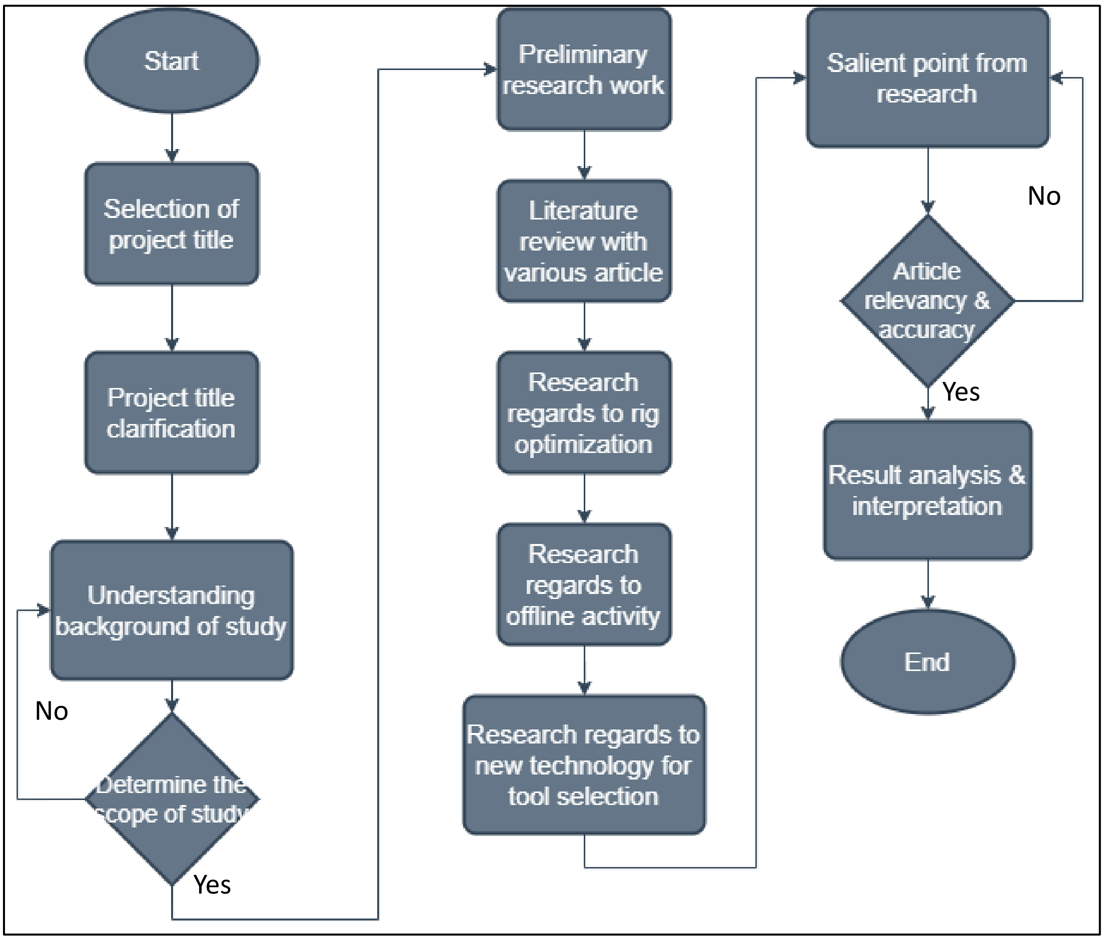

Figure 3.1: Project Overall Flowchart

Based on the figure above it shows the project flowchart for the overall process of this thesis writing. It only involves various research based on previous case study and the current project at field A. All the project initiative to cut the cost is record and capture so that the future project can refer to this lesson learn and have a better preparation for any risk mitigation. This will result for a better project planning which will ultimately utilize the budget from rig optimization, offline activity and new technology for tools selection.

This project has been carried out for approximately 12 weeks which is quite a limited time, but with this constraint does not mean all the data given is weak which all the articles have been analysed and validate accordingly. The project started with a title selection which with the current operation at Field A for partial P&A and workover activities, the author sees the opportunity to grab any key findings which be able to utilize the cost budget. The 3 main objective have been identified which be able to optimize the cost for the whole operation at field A.

The first objective which is rig selection is due to high ODR which give a very significant impact to the whole budget of the operation. The right rig selection will surely give a good reflection of project management team which be able to choose the rig that give the lower ODR or the rig that will give highest productivity compared to the other rig. The rig selection much more affected by the cost, spaces, positioning, and capability of the hoisting system as mentioned in the previous chapter. There are various article regards to the whole rig selection which experience is the best tools for the operator to analyse and choose the best rig accordingly.

The second objective which determine and maximize offline activity is related to objective no 1 too. The more the offline activity can be done, the less rig time needed for the whole operation, hence the less budget required but the return of investment (ROI) is the same. Time is always a major factor in the oil and gas industry which every NPT would give a huge damage to the project cash flow. With optimize of the offline activity, the productive time will be maximize and the NPT will be minimize close to 0 days. There are limited number of research have been done previously regards to the offline activity which give some difficulty in this section in the thesis writing.

The third and last objective from this paper is to propose and justify any new technology for tool selection in the operation that is more efficient and reliable. There are an impressing number of research have been done regards to a new technology in the oil and gas industry especially from the service company. The advancement of the technology forces the player in the oil and gas to step up the game hence to manufacture a more sophisticated tools and equipment to drill the well. In this paper only 3 tools that have been discuss which is overshoot, packer & milling tools.

3.3 Project Gantt Chart

No.	Task/Week	Status	1	2	3	4	5	6	7	8	9	10	11	12
Phase 1: Introduction														
1	Project title selection	Complete												
2	Project title clarification	Complete												
3	Understanding the background study	Complete												
Phase 2: Design Framework														
4	Methodology of the whole project	Complete												
5	Develop the flowchart for the project	Complete												
Phase 3: Research														
6	Preliminary research work	Complete												
7	Literature review with various article of overview the whole project	Complete												
8	Research regards to rig optimization	Complete												
9	Research regards to offline activity	Complete												
10	Research on any new technology for tools selection	Complete												
11	Article accuracy and relevancy	Complete												
12	Salient point from the research	Complete												
13	Validate the research	In progress												
Phase 4: Result & Analysis														
14	Research analysis & interpretation	In progress												
15	Make a conclusion based on the research	In progress												
16	Recommend of the future improvement of current research	In progress												

Legend

Milestones

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Overview

In this chapter, it will discuss the result and discussion for the whole optimization in term of planning, design and operation for workover and partial P&A activities at Field A for the 3 stated objectives which are;

i. To determine the optimum rig selection for Workover and P&A activity that is compatible for the operation and maximize the cost saving.
ii. To determine and maximize offline activity that can be done prior to rig up.
iii. To propose and justify any new technology for tool selection in the operation that is more efficient and reliable.

This will highlighted in the 3 different sub section accordingly based on the 3 objectives of the whole project. In term of rig selection at field A, it is using Semi TAD due to its capability to operate during bad weather since the whole campaign was planned to be execute at the end of the year which is monsoon season at Malaysia region. It will discuss the cost and capability of the different rig that might be able to be choose for the workover and partial P&A activities.

For the second objective, the operation at field A have utilize some offline activity which are cut the tubing and set the tubing plug which will discuss in detail the whole activity and how both activities can optimize the whole operation at Field A. In term of optimization is how it can reduce the cost and minimize the expenditure of the whole project without jeopardize the whole operation. Safety will always be number 1 priority hence all the risk assessment has be done accordingly before the initiation of the whole operation.

Lastly, to achieve the third objective which propose and justify new technology for tools selection. The design optimization based on the operation at Field A which the new technology can help to ensure the project run as planned and have low risk of NPT due to tools fail to operate based on it respective function. There will be 3 tools proposed in this project which is packer, overshot and mill. The propose new technology in this project will only be discuss in brief on how it will help the whole operation increase it productive time.

4.2 Rig Selection

As discussed in the literature review, rig selection is crucial for economic reason due to very expensive ODR and in the operation at Field A, the Semi Tender Assisted Drilling Rig (Semi – TAD) is used for the operation. Since the operation at field A is partial P&A and workover there are 4 suitable candidate for the rig that is suitable for the operation which is Hydraulic Workover Unit (HWU), Jack-Up Rig (JUR), Semi Tender Assisted Drilling Rig (Semi – TAD) and drillship. This planning optimization are as important as the operation optimization for the whole activity to maximize the profit and reduce the overall cost.

Table 4.1: Rig selection for different parameter

Parameter/Rig	Hydraulic Workover Unit (HWU)	Jack-Up Rig (JUR)	Semi Tender Assisted Drilling Rig (TAD)	Drillship
Cost (USD) *Operating Daily Rate	15, 000 – 20, 000	90, 000 – 150, 000	70, 000 – 80, 000	500, 000 – 700, 000
Water Depth (ft)	400	400	800	10, 000
Hoisting Capacity (lbf)	460, 000	> 2, 100, 000	> 1, 000, 000	> 3, 100, 000
Pumping Capacity (bbls/min)	11 @ 3000 psi	> 18 @ 7500 psi	> 18 @ 5000 psi	> 18 @ 7500 psi
Rig Structure & Weight	Light & Modular	Cantilever type	Floater	Floater
Deck Loading	Less reaction load to	No load	More reaction load to	No load

	platform		platform	
Rig Footprint on Platform	Small	No footprint	Big	No footprint

Based on the table above, it shows comparison for 4 different rig for various paramater and the main parameter that will be discussi is the cost and the rig cpability. It shows that cost for hydraulic workover unit is the cheapest which is around 15 000 USD – 20 000 USD daily which the most expensive is drillship which is around 500 000 USD – 700 000 USD. This shows that workover operation in term of the expenditure is lowwer compare to other operation such as drilling which it can use the HWU.

The drillship is a very capable rig for deepwater operation but since the water depth at Field A is around 450 ft hence the choice of drillship will only cause huge amount of money spent and not worth the whole operation. The ODR for drillship is very expensive and since the operation at deep water and not ultra deep water opeation the selection of drillship is out of discussion. Jack-Up Rig have the almost similar capabilty like the Semi TAD but since the ODR is a bit higher than Semi TAD hence the selection of JUR also been canceled out. The operation for JUR also for around 400 ft which is for shallow water since the opearation at Field A is deep water, the JUR might not be suitable for the operation.

The operation at Field A has use Semi Tender Assisted Drilling Rig (Semi – TAD) which the ODR is around 70 000 USD – 80 000 USD which is quite expensive compare to HWU. The main reason why Semi TAD has been choose instead of HWU is the capability to operate during bad weather which the rig capable to withstand more strong sea current and wave. Wait on weather (WOW) is the most common reason for NPT as the operation of Field A is located at Malaysia region where the monsson season for northwest which Fiela A located is November until March. Operation of workover and partial P&A at Field A was planned during those monsoon season hence the Semi TAD is more suitable compare to HWU.

The Non Productive Time is main reason for the project to spent over budget since the ODR will remain the same which means the longer the NPT the more the operation will need to pay the rent for the rig itslef. Semi TAD have been choose intead of other rig due to its reasonable cost, capable to withstand bad weather better than HWU nad the rig capabilty itself to carry the operation for partila P&A and workover at Field A.

4.3 Offline Activity

There are 2 offline activity that have been executed at Field A at well XY which are cut the tubing at planned tubing cut and set the tubing plug at planned tubing plug to be set. These 2 activities will be discussed thoroughly on the operation and how both activities can give optimization for the whole operation at Field A. As stated, based on research that have been done, offline activity is defined as operationalizing an event concurrently with online activity at rig floor or prior of the online activity at rig floor, without compromising outcome of online activity and safety of personnel which can reduce flat time directly.

As discussed on how every time passed on the rig is like every penny spent for the whole operation due to ODR and it is very expensive especially at the offshore. Hence the capability of offline activity can reduce the flat time directly which will reduce the time on the rig hence the whole operation can save hundreds thousands of USD. For instance, by utilize offline activity such as cut tubing, which normally would take 48 hours of the operation had be done offline, resulted the operation completed 2 days early ahead. This will save up to 160, 000 USD for the rig cost only which does not include the personnel, equipment, and fuel consumption for the rig which the daily spread cost of the operation.

Instead of discussing both activities in different section, in this project for both offline activities it will simply discuss together due to both operation are occurring 1 after another. Both offline activity will be using wireline since the cutter that have been used is mechanical cutter which the depth of the cutter to be drawn down in the hole is more accurate since get the live data inside the well. Based on the operation at Field A, the tubing plug is set first inside the tubing then the tubing cutter will be Run In Hole (RIH) and cut the tubing few feet above the tubing plug.

Tubing cut and set the tubing plug or known as set deep plug for well XY at the Field A had been done using wireline which it results in good cut and reduce the rig standby exposure time. The details and procedure of the tubing cut and set the tubing plug conducted online are shown below;

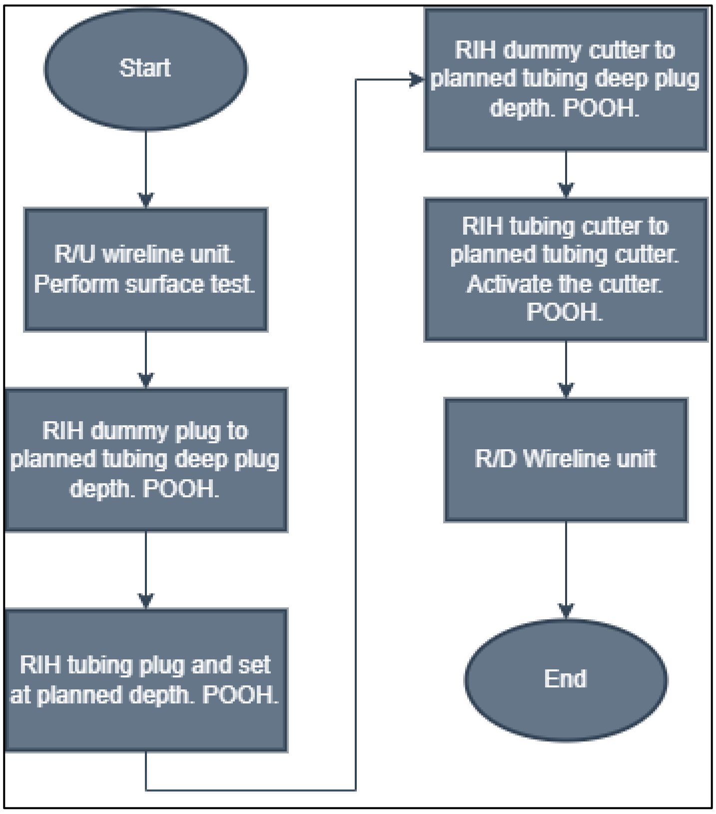

Figure 4.1: Procedure for set the tubing plug and cut the tubing

Based on the figure above it shows a common procedure for set the tubing plug and cut the tubing in the well. The operation starts by rig up the wireline unit which this is vary based on the project itself whereby for operation workover & partial P&A it will be using wireline unit. Briefly, wireline and slickline are almost similar where both can operate and live well, or dead will but the main different between this 2 are the wireline have a live data recorded instead of slickline.

Next once the wireline unit have been set on top at the rig, the operation continues to RIH the dummy plug which this is for mitigation purpose if there are some restriction in the tube which cause the downhole tools to stuck in the pipe and plug cannot be retrieve out, then it is less problem to cut the wireline and only dummy plug is left inside the downhole instead of real plug. This run only need to be run if the tubing is not cleared during slickline run. In short, this dummy operation is solely for tubing drifting.

Next, POOH the dummy plug and RIH the tubing plug to the set tubing plug depth and set the plug. The type of plug that have been used for this operation is disclosed due to its confidentiality. Once the tubing plug have been set then have been pressure tested whether the plug has been set at the right depth and be able to pass the pressure test, only then the operator will POOH the wireline.

Next the operation, continues to the second activity which is cut the tubing where once all the equipment has been make up at the rig floor, the cutter is RIH into the well to the planned cutting depth. This is a very common activity for partial P&A and workover which it to cut the tubing and retrieve the tubing out of hole. Since retrieve the tubing required a stronger hoisting system hence it cannot be done offline without the rig at the location. Once the cutter is located at the planned depth, the operator will activate the cutter and it will cut the tubing.

The operation at Field A have choose and use mechanical cutter to cut the tubing. This is due to the capability of the cutter to cut the tubing without hazardous chemical or ballistic which can reduce risk impact to the environment. Despite being far slower than chemical or explosive cutters, these cutters can still be operated with standard machinery. The pipes made of softer, lower alloy with narrower surface work better with the mechanical cutters. It is more challenging to cut thick and high alloy pipes with a mechanical cutter.

To relate how utilize offline activity can give optimization of the whole project at field A for workover and partial P&A is in terms of how it can reduce the rig time. The average of both cut tubing and set the deep plug in the tubing time is around 38 hours which the details can be shown in the table below;

Table 4.2: Duration for cut tubing and set plug activities.

No	Activity	Hours	Days
1.	R/U wireline unit. Perform surface test.	8	0.33
2.	RIH dummy plug to planned tubing deep plug depth POOH.	5.5	0.23
3.	RIH tubing plug and set at planned depth. POOH.	5.5	0.23
4.	RIH dummy cutter to planned tubing cut depth. POOH.	5.5	0.23
5.	RIH tubing cutter to planned tubing cut	7.5	0.31

	depth Activate cutter. POOH.		
6.	R/D wireline unit.	6	0.25
Total		38	1.58

Based on the table above, it shows the typical duration that will be needed for the cut tubing and set the tubing plug from rig up the wireline unit until rig down the wireline unit. This duration highly dependent on the depth and inclination of the well which the deeper the well the longer the time required to RIH and POOH which ultimately will result longer operation.

In term of optimization, to be able to cut 1.58 days is a huge amount of cost saving since the ODR only is very expensive. For rig cost only, lets take the ODR for Semi TAD is around 80 000 USD. Which if 1.58 days then the total cost saving for the offline activity is shown in the equation below;

$$ODR = 80,000\ USD$$

$$Offline\ activity\ duration = 1.58\ days$$

$$Cost\ Reduction = 80\ 000 * 1.58 = 126,400.00\ USD$$

Where;

ODR = Operating Daily Rate

The equation above is shows for the rig cost only which can save up to 126, 400 USD. This is a very good cost saving as every initiatives which can help to reduce the whole cost should be take into consideration. In term of spread cost it can be shown in the equation below;

$$Total\ Planned\ AFE\ Cost = 3,000,000\ USD$$

$$Total\ Planned\ Days = 15.00\ days$$

$$Daily\ Spread\ Rate = \frac{Total\ Planned\ AFE\ Cost}{Total\ Planned\ Days}$$

$$Daily\ Spread\ Rate = \frac{3,000,000}{15.00}$$

$$Daily\ Spread\ Rate = 200,000$$

$$Offline\ activity\ duration = 1.58\ days$$

$$Cost\ Reduction = 200,000 * 1.58 = 316,000.00\ USD$$

Where;

AFE = Approved for Expenditure

Take notes that all the values taken is approximately closed to the real values where the key point take aways from this chapter is to show on how offline activity can help to reduce the overall cost of the project. Based on the equation above, it shows how daily spread cost and how with only 38 hours which is 1.58 days can save up 316, 000.00 USD. This is a very significant amount of cost saving whereby this will help to ensure the project is within the budget and more cost savings can be done throughout the whole project at Field A.

4.4 Tools selection

In this last sub section for this chapter, it will discuss on the third objective of the project which is to propose and justify new technology for tool selection in term of design optimization for the whole workover and partial P&A activities at Field A. There will be 3 tools that will discuss in this topic which are packer, overshoot and mill. The one that will be propose here is just an overview of the tools for the design optimization which mean how these tools ensure the activity run as planned and have low risk of tools failure.

4.4.1 Production Packer, Thru Tubing Inflatable Retrievable Packer

The first tool that will discuss here is the packer which function is to isolate the lower part of the reservoir. The packer mostly used from the completion team specifically located at the production zone which once production packer is install there will create an anulus between the outer production casing and inner part of production tubing, annulus A. The annulus A is as important as other annulus too as the packer must be pressure tested to ensure there are no communication between the lower part of the production zone and upper part of the production zone.

This tool is chosen to be discuss in this paper as the operation at Field A required the permanent production packer to be retrieve before the perforation zone can be cement for partial P&A to temporary abandon the well. This part should be highlighted to the completion team during designation of well completion to take into consideration the packer design as there is probability to retrieve the tubing out to the surface for workover operation.

The proposed production packer to be used for future packer in the completion well is from Baker Huges, Thru Tubing Inflatable Retrievable Packer which is capable to be retrieve. Hence this will cut off the need to mill the packer which the operation has given various problems since milling operation is not as easy as planned and milling rate is very slow which lead to longer operation hours for the operation.

Figure 4.2: Thru Tubing Inflatable Retrievable Packer

The figure above shows one of the production packer develop from Baker Huges, Thru Tubing Inflatable Retrievable Packer with Hydraulic Lock enables stimulation and remediation procedures in wells without requiring the pulling of the production tubing. The packer has an inflatable packing element that is designed to fit through production tubing, pack off the casing below, and, when deflated, contract back to its original size, allowing the packer to be retrieved via the tubing. The Packer may be used with both threaded and coiled tubing because it only allows for a small amount of tubing manipulation and operates on tubing pressure.

A hydraulic lock mechanism on the packer prevents the shear screws from being loaded by supporting the packer's weight as it descends into the hole. The packer mandrel can be moved to the equalizing position and onto the release position by manipulating the Hydraulic Lock, which releases when pressure is applied to set the packer. If preferred, the packer can be operated without the hydraulic lock.

A pull equalization function, typically utilized before deflation, is a feature of the Packer. Tension is applied to the tube to shear the screws and open apertures above the packer, achieving the appropriate equalization across the packer. In order to deflate and retrieve the packer, set down weight is provided to it once equalization has taken place, and then tension is applied again to the packer to the shear release sleeve shear screws.

One of the features that this packer that will give better operation is single trip to set, treat and release enables more efficient operation. This will surely remove the need to mill the packer and reduce the total operation time. More details of this product specification are attach in the appendix.

4.4.2 Overshot, Bowen™ Wide Catch Overshot

Fish is something that is something that has the probability to produce during the operation in the well included operation at Field A for workover and partial P&A activity whereas there always a tendency for the downhole tool to stuck in the well and need to be parted to retrieve the wireline. The stuck pipe or tool to be stuck in a well is always a thing that operator would like to avoid at any means as the operation will be stop and this will create NPT. In this sub chapter by giving the best fishing tool, the NPT time would be able to minimize during fishing operation. The faster the fish to be fish to the surface, the faster the operation can be continue and this will result lower NPT for the whole operation.

National Oilwell Varco, NOV Inc has develop one fishing tools called Bowen™ Wide Catch Overshot which is shows a great feature to successfully fish the fish downhole. The company claims, compare to the other overshoot in the market, this tools offers an extended range that's up to 4 times greater. It capable to externally engager, pack off and pull a fish that have a very bad condition.

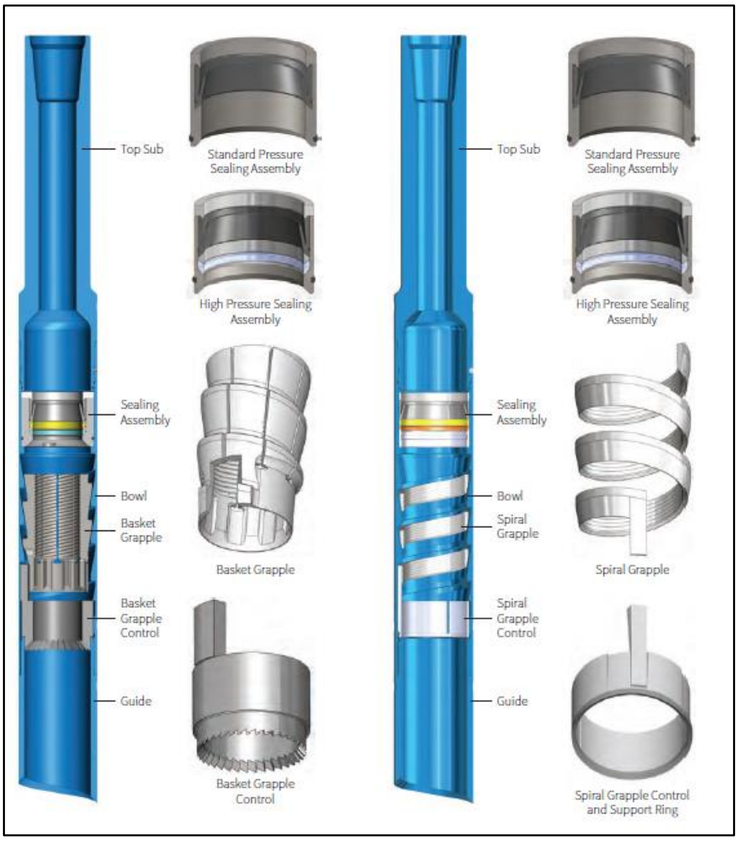

Figure 4.3: BowenTM Wide Catch Overshot

The figure above shows the component of overshot from NOV, which consist of different components from top sub, sealing assembly and guide. In addition to the large catch range, the overshot has the ability seal across very large extrusions gaps at either standard or high pressure and provide full circulation through the fish. This will make the fish to be easier to be lift from the place where it stuck.

The function of this overshot is almost similar with the other overshot in the market which are to engage, pack off and retrieve the fish in the downhole. The mechanism of this overshot is it will engage at the neck of the fish which other words swallow the fish. The example of the fish which this tools be able to engage are stuck or lost tubing, casing coupling, casing and tool joint. The reason why this overshot has been proposed instead of other overshot in this project is the special features that be offer to the user.

One of the concern for fishing tools is the tendency for the connection to loosen during engaging and releasing, causing the tool to back off especially in the high-profile area. The Bowen^{TM} Wide Catch Overshot, give the solution by top sub to bowl connection has 3 equally spaced set screws that are inserted through the threads. In the event, that the torque is great enough to break the connection, the threads will be galled by the set screws, preventing the connection from backing off.

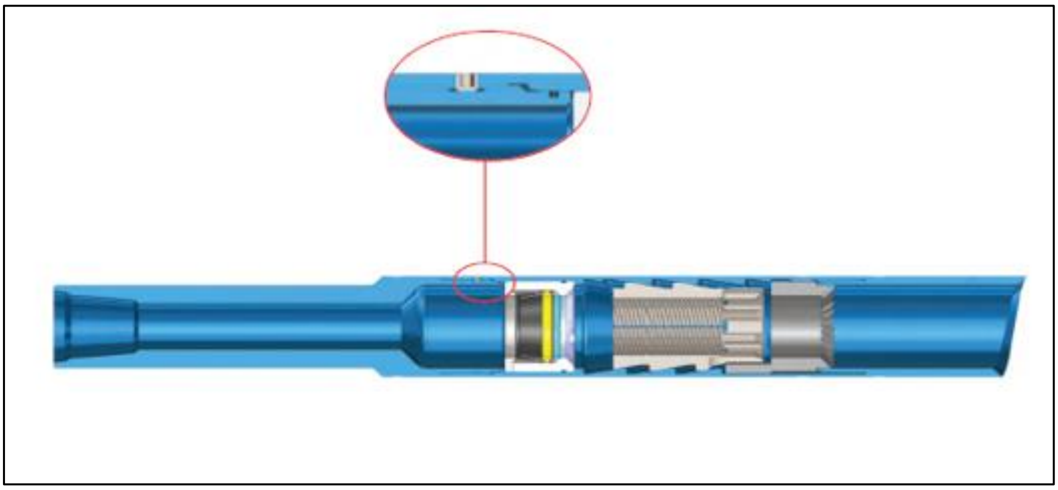

Figure 4.4: 3 equally spaced set screws at top sub

By using a good design tools, the risk of tools failure is lower, and this can reduce the NPT for the whole operation. The specification of the product is include in the appendix

4.4.3 Mill, MillSmart^{TM} Technology

One of the milling function is the operation that will always be part of contingency plan once all the effort to fish downhole tools is failed. There is some condition where the fish can be left in the hole and some that need the fish to be retrieve to the surface such as the workover operation at Field A where the permanent packer need to be retrieve out for well recomplete in the future hence the only option left to retrieve the permanent packer is by mill the packer.

Weatherford which is known for its specialty in design and manufacture a downhole tools in oil and gas has develop a new mill technology call MillSmart^{TM} Technology. The world's largest and most seasoned supplier of milling and fishing services, Weatherford, has created and polished a wide range of tested products, services, and technical resources that together make up its engineering approach to milling, known as MillSmart. MillSmart technology is founded on an enormous quantity of milling data that Weatherford's global Performance Tracking System, which is utilized to develop best practices for nearly all usage.

For work planning, MillSmart's proprietary hydraulic modelling software able to provides with the most accurate possible preview of a suggested milling operation. HydraPro™, HydraForce™, Hydra-Cut™, and HydraBoost™ software suite is designed for high-profile well designs that require pre-job planning, such as extended-reach, deepwater, horizontal, high-angle, high-temperature/high-pressure, and others.

Weatherford CustomCut inserts for milling or cutting are accessible in a range of shapes and sizes. Our sophisticated Weatherford-certified welders and mill engineers guarantee a dependable and long-lasting cutting structure for each rotary and mill shoe that we manufacture. CustomCut inserts come with a unique negative chip and rake. breaker design that successfully separates the cuttings. This offers smaller, lighter, and thinner cuts that may be made swiftly and readily flowed to the top and around the hole to improve the cleaning process, faster penetration rates and higher efficiency.

A significant performance improvement is provided by MillSmart technology and CustomCut carbide inserts, which use components and designs that support a holistic system process approach. The CustomCut 100, 200, and 300 series of special-application carbide milling products are the result of concentrated research and engineering efforts, as well as considerable field experience and case studies.

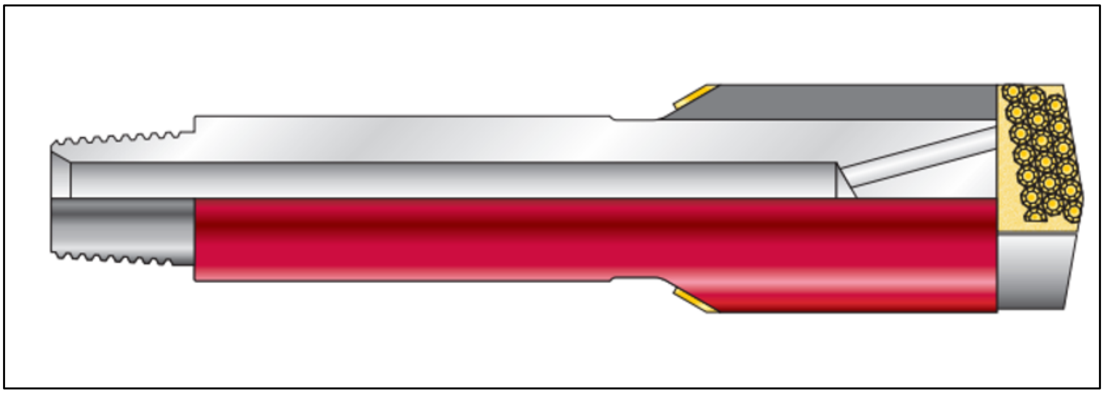

Figure 4.5: ClearCutTM MPMill

The purpose of Weatherford's ClearCut MP mill is to manufacture composite bridge plugs that meet industry standards. It is designed to work best with Weatherford's downhole motors for maximum efficiency and quickest penetration rate. Durable CustomCutTM tungsten carbide inserts are used to dress the mill, reducing drill times and providing uniformly sized, readily removable debris bits. The CustomCut inserts come in a range of shapes and come with unique rakes and chip breakers to provide uncompromising consistency.

The features that make this milling tool is superior compare to the other milling tools in the market are;

- The sturdy, five-bladed mill head is designed to last as long as possible and work as efficiently as possible to provide dependable, affordable milling operations.
- The optimized alignment of the CustomCut inserts produces fine debris particles of consistent sizes, which facilitates debris removal and expedites the milling operation, prolonging the life of the mill to reduce additional trips when milling multiple plugs.
- The blades, when inset with CustomCut tungsten carbide inserts, are configured to reduce torque and minimize drill time.

The details and specification of the product are attach in the appendix.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, the objective of this project is achieve which the optimization in term of planning, design and operation for workover and partial P&A activities at field A. There are 3 objectives from this paper which are to determine the optimum rig selection for workover and partial P&A activities that is compatible for the operation and maximize the cost saving, to determine and maximize offline activity that can be done prior to rig up and to propose and justify any new technology for tool selection in the operation that is more efficient and reliable.

The first objective is achieve whereby in this project based on research form various article, magazine and case study, comparison had been done for 4 different rig and it was justify and why Semi TAD has been choose for operation at Field A. The cost and capability of the rig have been compare and it shows Semi TAD has shows the best criteria for the partial P&A and workover operation at Field A. This has optimize the operation in term of Operating Daily Rig, which have avoid any unnecessary NPT due to WOW.

The second objective which to determine offline activity also able to achieve whereby it shows how only 2 offline activity which are cut the tubing and set the tubing plug has cut the rig time for approximately 38 hours. This offline activity has cut the overall cost for the whole project at Field A almost, 316,000.00 USD. It shows how offline activities have optimized the whole operation at Field A for workover and partial P&A activities.

Lastly there are 3 new or existing technology have been proposed in this paper which can help to ensure better project execution. The 3 new technology are Thru Tubing Inflatable Retrievable Packer from Baker Huges, Bowen™ Wide Catch Overshot from NOV Inc, and MillSmart™ Technology from Weatherford, there are no comparison done between different tools but the proposal more on the features and benefits of the tools itself only. A better tools would definitely give a better project success probability.

5.2 Recommendation

There are few recommendation from this paper whereas a thorough study should be done in the 3-objective given which is in term of rig selection, offline activity, and the tools selection. First and foremost, in term of rig, there should be able to study for the new design of rig which might be able to withstand rough weather especially during monsoon season. This is especially for offshore location since the rig structure plays a major role whether the activity can be done during bad weather or not. Next, there are very few articles regards to the offline activity as there are very minimum number of study done on previous project that able to record every offline activity that have been done which be able to cut the rig time. The offline activity will be able to give significant impact to the rig time which will be able to cut the cost for the whole operation. Lastly, in term of new tools selection, a more details analysis and comparison might be able to be done in the future to give a more valid and strong justification for the new tools to be introduced in the operation.

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APPENDICES

Appendix A: Thru Tubing Inflatable Retrievable Packer Specifications

Baker Hughes

Size – Tool OD (in.)	1.69	2.13	2.50	3.00	3.38	4.25	5.38	5.75
Chassis OD (in.) (mm)	1.69 (43)	2.13 (54)						
Inflatable Element Length (in.) (ft)	48.00 (4.00)	66.13 (5.51)						
Tool Length (in.) (ft)	108.36 (9.03)	142.80 (11.90)						
Tensile Rating (above the inflatable element) (lb) (kg)	18,700 (8,500)	34,250 (15,568)						
Tensile Rating (through mandrel) (lb) (kg)	5,300 (2,410)	14,900 (6,773)						
*Maximum Pressure Rating (psi) (bar)	5,500 (379)	6,000 (414)	6,500 (448)	8,000 (552)	8,500 (586)			
Maximum Temperature Rating (°F) (°C)	300 (149)							
Maximum Expansion ID (in.) (mm)	4.892 (124)	6.765 (172)	8.681 (221)		9.760 (248)		12.415 (315)	
Maximum Restriction to pass through (in.) (mm)	1.75 (44)	2.19 (56)	2.56 (65)	3.06 (78)	3.44 (87)	4.31 (109)	5.44 (138)	5.81 (148)
Service	Standard & H_2S							

*This pressure is rated at minimal expansion. Pressure ratings decrease as element expansion increases.

bakerhughes.com

Appendix B: Bowen™ Wide Catch Overshot Specifications

Bowen™ Wide Catch Overshot

11. Specifications and Replacement Parts

Specifications

Maximum Catch Size (Spiral)		**3 21/32 in.**	**4 3/8 in.**	**6 1/2 in.**	**7 in.**	**8 in.**	**10 1/8 in.**
Maximum Catch Size (Basket)		3 1/16 in.	4 5/8 in.	5 5/8 in.	6 1/4 in.	7 1/2 in.	9 in.
Overshot OD		4 11/16 in.	5 3/4 in.	7 3/8 in	8 1/8 in.	9 1/8 in.	11 3/4 in.
Standard Box Connection		2 3/8 in. IF Box	3 1/2 in. IF Box	3 1/2 in. IF Box	4 1/2 in. IF Box	4 1/2 in. IF Box	6 5/8 in. REG Box
Complete Assembly	**Part No.**	506586	506366	507460	506458	506585	507331

Replacement Parts

Top Sub	**Part No.**	506493	506148	507405	506249	506292	507192
	Weight	45 lbs	72 lbs	79 lbs	152 lbs	158 lbs	283 lbs
Bowl	**Part No.**	506491	506149	507409	506250	506296	507228
	Weight	25 lbs	29 lbs	40 lbs	60 lbs	66 lbs	141 lbs
Spiral Grapple	**Part No.**	506494	505565	507457	506251	506297	507195
	Weight	5 lbs	6 lbs	9 lbs	8 lbs	23 lbs	23 lbs
Spiral Grapple Control	**Part No.**	506504	505567	507443	506253	506298	507230
	Weight	1 lbs	2 lbs	3 lbs	4 lbs	5 lbs	10 lbs
Support Ring	**Part No.**	506661	506662	507456	506659	506660	507456
	Weight	0.1 lbs	0.1 lbs	0.5 lbs	0.1 lbs	0.1 lbs	0.1 lbs
SP Seal Housing	**Part No.**	See page 18	505578	507411	See page 19	See page 20	-
	Weight	7 lbs	14 lbs	15 lbs	22 lbs	25 lbs	-
Retainer	**Part No.**	506478	505576	507429	505981	506348	506887
	Weight	1 lbs	1 lbs	0.44 lbs	2 lbs	5 lbs	4 lbs
Packer	**Part No.**	See page 18	See page 18	507464	See page 19	See page 20	See page 20
	Weight	0.25 lbs	0.25 lbs	0.28 lbs	0.25 lbs	0.25 lbs	0.5 lbs
O-Ring (Housing)	**Part No.**	See page 18	See page 18	See page 19	See page 19	See page 20	See page 20
	Weight	0.1 lbs	0.1 lbs	0.1 lbs	0.1 lbs	0.1 lbs	0.1 lbs
O-Ring (Top Sub/ Ext Sub)	**Part No.**	568154	568158	568166	568168	568172	568275
	Weight	0.1 lbs	0.1 lbs	0.1 lbs	0.1 lbs	0.1 lbs	0.1 lbs
Set Screws (Qty. 3)	**Part No.**	506187/005	506187/005	507415/005	506187/005	506187/005	506187/005
	Weight	0.1 lbs	0.1 lbs	0.1 lbs	0.1 lbs	0.1 lbs	0.1 lbs
Standard Guide	**Part No.**	6667	6121	507424	9226	A5272	5336
	Weight	13 lbs	23 lbs	38 lbs	40 lbs	45 lbs	88 lbs

Basket Grapple Parts

Basket Grapple	**Part No.**	506494	505565	-	506251	506297	507195
	Weight	15 lbs	24 lbs	-	35 lbs	35 lbs	57 lbs
Basket Mill Control	**Part No.**	506502	505568	-	506252	506299	507292
	Weight	5 lbs	5 lbs	-	20 lbs	20 lbs	29 lbs

High Pressure Sealing Assembly

HP Seal Housing	**Part No.**	See page 18	505903	-	See page 19	See page 20	506883
	Weight	5 lbs	14 lbs	-	22 lbs	25 lbs	4 lbs
Retainer	**Part No.**	506478	505576	-	505981	506348	506887
	Weight	1 lbs	1 lbs	-	2 lbs	3 lbs	4 lbs
Seals	**Part No.**	See page 18	See page 18	-	See page 19	See page 20	506888
	Weight	0.25 lbs	0.25 lbs	-	0.25 lbs	0.25 lbs	0.5 lbs
Non-Extrusion Ring	**Part No.**	See page 18	505904	-	See page 19	See page 20	506886
	Weight	0.25 lbs	0.25 lbs	-	0.25 lbs	0.25 lbs	1.5 lbs
Solid Ring	**Part No.**	See page 18	505905	-	See page 19	See page 20	506885
	Weight	0.1 lbs	0.1 lbs	-	0.1 lbs	0.1 lbs	0.86 lbs
C-Ring	**Part No.**	See page 18	505906	-	See page 19	See page 20	506884
	Weight	0.1 lbs	0.1 lbs	-	0.1 lbs	0.1 lbs	1 lbs

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Appendix C: ClearCut™ MP Mill Specifications

Weatherford®

Thru-Tubing Intervention

ClearCut™ MP Mill

Specifications

Casing/Tubing Size (in./*mm*)	Top Pin Connection	Mill Blade OD (in./*mm*)
2-3/8 *60.3*	1-in. AMMT	1.750 or 1.947 *44.45 or 49.45*
2-7/8 *73.0*	1- or 1 1/2-in. AMMT	1.971 or 2.347 *49.54 or 59.61*
3-1/2 *88.9*	1 1/2-in. AMMT	2.477 or 2.943 *62.92 or 74.75*
4-1/2 *114.3*	2 3/8-in. PAC or 2 3/8-in. Reg	3.625 or 3.965 *92.08 or 100.71*
5 *127.0*	2 3/8-in. PAC or 2 3/8-in. Reg	3.875 or 4.500 *98.43 or 114.30*
5-1/2 *139.7*	2 3/8-in. PAC or 2 7/8-in. Reg	4.545 or 4.919 115.44 or 124.94
7 *177.8*	2 3/8-in. PAC or 2 7/8-in. Reg	5.795 or 6.500 *147.19 or 165.10*

Note all sizes are suggested; care must be taken to ensure that mill bodies are fishable and mill blade OD will pass any profiles in the well.

weatherford.com 2