Author: Joseph Patrick Ndiga Ngue, BSc

Master Thesis 2016:E12 supervised by
Univ.-Prof. Dipl.-Ing. Dr.mont. Gerhard Thonhauser

Level 3 Casing Drilling in a Mature Field Environment

DEPARTMENT PETROLEUM ENGINEERING

MONTAN UNIVERSITÄT

DEDICATION

This thesis is dedicated to the Almighty God, who was my guide during my studies.

Affidavit

I declare in lieu of oath that I wrote this thesis and performed the associated research myself using only literature cited at the end of this volume.

Eidesstattliche Erklärung

Ich erkläre an Eides statt, dass ich diese Arbeit selbständig verfasst, andere als die angegebenen Quellen und Hilfsmittel nicht benutzt und mich auch sonst keiner unerlaubten Hilfsmittel bedient habe.

....

Joseph Patrick Ndiga Ngue

Leoben, August 2017

Acknowledgements

First, I would like to express my deep gratitude to my advisor Prof. Gerhard Thonhauser who has supported me throughout my thesis with his pertinence, motivation and knowledge. His guidance helped me in all the time of research and writing of this thesis.

Besides Prof. Thonhauser, I would also like to thank my thesis committee of OMV Austria E & P, department of drilling engineering in Gaenserndorf: Dr. Wilhem Sackmaier who provided the subject, DI Thomas Tuschl and DI Stefan Knehs for their insightful comments which gave me the incentive to widen my research to include various perspectives.

My sincere thanks also go to Mr Ming Zo Tan from the Weatherford Global Drilling with Casing Product Champion in Houston and to Mr Ali Issa from Schlumberger Continental Europe in Germany for providing me some data and important information to conduct my thesis.

During my studies in Leoben, many people and friends were helpful to colour my life. I have to acknowledge to Andrea & Alex Radinger, Gudrun & Holger Beerman, Pastor Julia & Thomas Moffat of Evangelische Kirche (Lutheran Church) in Leoben and Pastor Daniela Kern of Evangelische Kirche of Troifaiach for their mental and financial support.

Finally I would like to thank my family: my parents Emmanuel Ngue and Berthe Chantal Ngue, my brother Ivan Lionel Ngue, my sisters Friquette Ngue, Danielle Ngue and Diane Francoise Ngue for theirs prayers throughout my studies in Leoben.

Abstract

The drilling industry is continually searching for new technology and engineering advancements to improve drilling efficiency at the lowest cost. Drilling-with-Casing (DwC) is one of these new technologies which has been utilized to mitigate drilling hazards such as wellbore instability, lost circulation and eliminating problematic surge and swab effects seen with conventional drilling methods. Most of the current DwC activities are focusing on drilling vertical wells, but recently interest in Drilling-with Casing in directional wells, which is by definition the Level 3 casing drilling system has drastically increased as the process for drilling straight holes become proven, and more tools are becoming available. This work describes, analyses and evaluates the Level 3 casing drilling in a mature field environment like the Vienna Basin by means of solving the problems encountered by OMV Austria in the borehole conditions during check trips where lose of time and money occurred

In the first part, history of casing drilling system, casing drilling applications, casing drilling types and operations are presented in order to see the development and the evolution of casing drilling technology to date.

The thesis then focuses on screening the market for available Level 3 casing drilling technology. Schlumberger and Weatherford technologies were chosen and the screening included offset data analysis of existing projects.

Furthermore, a combination of technical and economic feasibility was evaluated to implement the Level 3 casing drilling in the Vienna Basin. For this, the boundary conditions within OMV Austria were set by the selection of a conventional well, E3. The economic feasibility study was performed for the cost estimation and control using the probabilistic approach.

The comparison of the results of the simulations of E3, Weatherford and Schlumberger led to the possibility to apply the Level 3 casing drilling in the Vienna Basin. The Under Reamer (UR) arms design needed to be improved by modifying the gauge protection and exposed cutting area.

The Bottom Hole Assembly (BHA) specially designed with a motorized Rotary Steerable System (RSS) will provide a smooth well profile with minimal well tortuosity that could affect casing fatigue life and therefore, fewer torque requirements and casing connections. Proper logistics and planning are also central to an outstanding casing directional drilling operation.

Zusammenfassung

Die Tiefbohrindustrie ist fortwährend auf der Suche nach neuen Technologien und fortgeschrittenen technischen Methoden um den Wirkungsgrad des Bohrens bei niedrigeren Kosten zu verbessern.

Drilling-with-Casing (DwC) ist eines der neuesten Technologien, die angewendet wird, um die Risiken beim Bohren, wie z.B. Bohrlochinstabilität und Lost-Circulation, zu verhindern. Durch diese Methode werden auch Probleme wie „Surge“ und „Swab“, die beim konventionelen Bohren auftreten können, eliminiert. Viele der DwC – Anwendungen finden in vertikalen Bohrungen statt. Jedoch steigt in jüngster Zeit das Interesse, diese Technologie beim horizontal gesteuerten Bohren – Level 3 Casing- Bohren – einzusetzen. Dieser Anstieg an Interesse hängt damit zusammen, dass durch die fortschreitende Technologie die notwendigen Werkzeuge verfügbar werden. Daher beschreibt, analysiert und evaluiert diese Arbeit der Level 3 Casing – Bohren in einem Brownfield, wie z.B. in dem Wiener Becken. Das Ziel besteht darin, Lösungen zu den Problemen, die der OMV Austria beim Bohren, während eines „Check – Trips“ begegnen, zu finden, da diese nicht nur viel beanspruchen, sondern auch die Bohrkosten steigen lassen.

Der erste Teil dieser Arbeit beschäftigt sich mit der Geschichte des Casing-Bohrsystems, den verschiedenen Arten und Anwendungen des DwC. Auch die Einsätze dieser Technologie, die diese Entwicklung bis heute unterstütz haben, werden ebenfalls behandelt.

Weiteres konzentriert sich diese Arbeit auf das Screening der am Markt verfügbaren Level 3 Casing-Bohren Technologien. Die Technologien von Schlumberger und Weatherford wurden ausgewählt und das Screening beinhaltet auch „Offset“ Datenanalyse vom vorhandenen Projekte.

Des Weiteren wurde sowohl eine technische als auch wirtschaftliche Machbarkeitsanalyse der Implementierung des Level 3 Casing-Bohrens in dem Wiener Becken durchgeführt. Demzufolge wurde eine konventionelle Bohrung (E3) der OMV Austria als Randbedingung herangezogen. Die wirtschaftliche Machbarkeitsanalyse erfolgte mittels Kosteneinschätzung und Kostenlenkung anhand von probabilistischem Ansatz.

Der Vergleich der Ergebnisse aus den Simulationen von E3, Weatherford und Schlumberger führten zu der Möglichkeit der Anwendung des Level 3 Casing-Bohren in dem Wiener Becken. Der Entwurf des „Under Reamer“ Lappens ist durch die Modifizierung des Messuhrschutzes und der freilegenden Bohrgutsfläche zu verbessern.

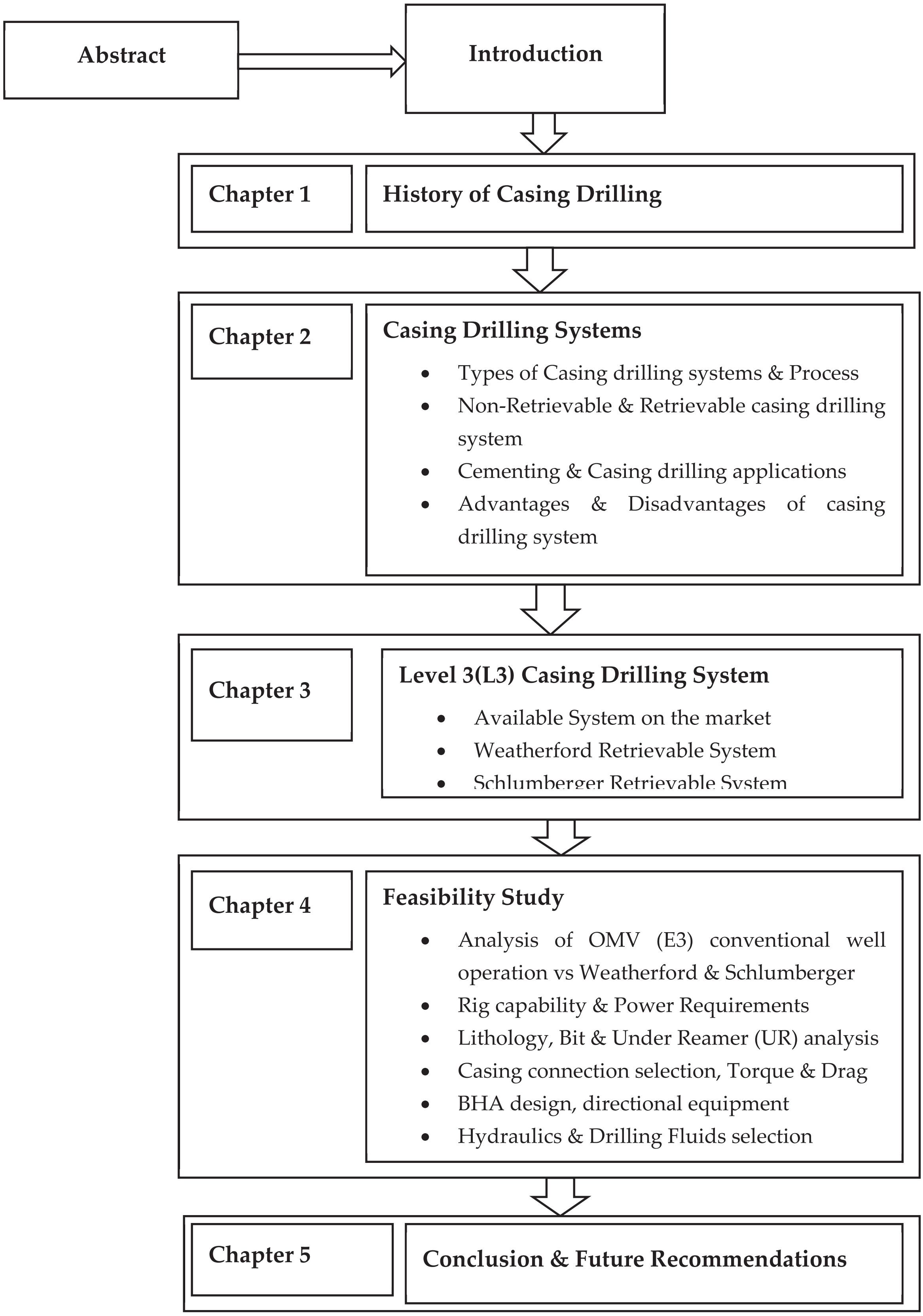
Ein Bohrgestänge mit RSS Design wird ein gleichmäßiges Bohrprofil mit minimalen Bohrtortuosität, die Auswirkungen auf die Ermüdung und Lebensdauer des Casings haben kann, liefern. In weiterer Folge, führt das RSS zu einem geringeren Gebrauch an Drehmoment und „Casing-Connectors“. Eine gute, sinnvolle Planung und Logistik sind essentiell für ein ausgezeichnetes horizontal gesteuertes Casing-Bohren

Table of Contents

List of Figures

List of Tables

Structure of the Thesis



Introduction

In the effort to secure future oil and gas resources, exploration and production, operators are forced to face wells profile that cannot be accessed with traditional drilling, either due to technological limitations or to extremely high costs. These new well profiles require a practical method such as Drilling-with Casing (DwC) in order to solve these particular drilling problems and reduce drilling costs.

Casing drilling is a process in which a well is drilled and cased simultaneously. For the last 20 years, this technology has evolved and gradually matured to address various drilling problems challenges such as the possibility to drill from one casing shoe to the next casing shoe in directional holes including a build and turn section, the surface section, intermediate or technical section and even production section.

The Level 3 casing drilling which is a retrievable assembly including directional drilling is such a challenge. Interest in directional drilling has recently started to increase as the process for drilling straight holes become proven.

The inability to consistently follow a prescribed well path and to hit and to stay within the targets has been the most significant directional drilling problem identified by operators like OMV Austria. The consequences of excess tortuosity include increased drilling times, increased stress on downhole equipment leading to tool failures, increased torque and drag leading to limited reach for extended reach wells and future production problems such as unanticipated high water production.

Industry requires methods to solve such situations. Moreover, motor systems with tools like the motorized rotary steerable systems (RSS) and the positive displacement motor (PDM) are needed to optimize the directional drilling.

The aim of this thesis is to summarize these different approaches of the Level 3 Casing Drilling, check the technical and economics feasibilities and finally deliver a recommendation on the most fitting technology for the upcoming drilling campaign in OMV Austria. Therefore, offset available data of the 9 5/8″ casing intermediate section of a conventional well E3 will be reviewed and compared with the present day Level 3 casing drilling technologies marketed by Schlumberger and Weatherford.

The decision to implement the Level 3 casing in Austria will be based on this feasibility study.

1.History of Casing Drilling System

The concept of Casing Drilling System was introduced to the drilling industry in order to reduce trip time and operating costs.

The first patent of casing drilling dates back to 1890 (1), which involved a rotary drilling process for drilling the well with the casing and retrieving the hydraulically expendable bit.

In 1926, another patent was introduced, which incorporated a retrievable and re-runnable casing bit in its system. (2).

In the 1930s, work on developing retrievable drilling tools began in the former Soviet Union, but details were cloaked in the secrecy due to the relationship between USSR and the West. (1).

In the 1960s, Brown Oil Tools Company was the first oil company to carry out extensive work on casing drilling. They published a revolutionary patent where a Casing Drilling System was composed of downhole and surface tools. Those tools were used to drill with the casing and a retrievable bit. (2). Their components included casing centralizers, wire line retrievable drilling assembly, Under Reamer (UR), casing drive tool and a top drive. This patent encouraged the development and the commercialization of the top drive.

In the late 1990s, oil companies, such as Tesco Corporation developed the Casing Drive System (CDS). Their technology was welcomed by the majority of the drilling industry, due to the number of wells drilled in that period. For example, in the Western province of Canada in Alberta, Bob Tessari who is well known for his publications in the casing drilling area, made a breakthrough with his team of engineers by introducing the first fit purpose drilling rig in 1997. They drilled several wells in Western of Canada with this technology and the results were highly satisfactory leading to the reduction of well costs and reduction of Non Productive Time (NPT). (1). The fundamental premise behind developing a casing drilling system is that well costs can be reduced if the casing is installed as the well is drilled. A redesign of surface rig equipment and down hole systems is required to achieve this objective.

Costs savings can then result through the elimination of purchasing, handling, inspecting, transporting and tripping the drill string while reducing hole problems that are associated with tripping. In addition, significant savings can be gained through a reduction of rig equipment needs and operating costs.

It's also important to note that casing drilling did not find a wide application due to the technological difficulties experienced in the late 19 th century and a major part of the 20 th century.

Major technological challenges faced by oil companies in order to develop practical solutions for casing drilling are for example: (3).

- The rotation of the casing using a top drive system.
- Gripping and supporting the casing string without using its threads.
- Locking a wire line retrievable drilling assembly to the bottom of the casing.
- Developing a practical Under Reamer (UR) to open the hole enough to accept the casing string.

In June 2012, an announcement was made by Schlumberger on their website, stating that the company had acquired Casing Drilling from Tesco Corporation. The two companies have a long term agreement. Tesco Corporation will provide the CDS equipment to Schlumberger in order to support the latter's casing drilling projects. (4).

2. Casing Drilling Systems

2.1. Types of Casing Drilling Systems

The present day Casing Drilling technology and field services as described by Table 1, below, is composed of three different systems which are marketed at five levels:

Casing Drilling System	**Components**	**Level of design**
Non - Retrievable System	• Simplest and most commonly used type • String rotation required • No directional trajectory change capability • PDC Bits	Level 1 & 2
Retrievable System	• Motor or Casing rotation used • Multiple runs per section • Directional and straight hole drilling.	Level 3
Liner Drilling System	• Liner Hanger • Advanced retrievable BHA which includes a top drive system	Level 4 & 5

Table 1: Casing Drilling System (5) (6) (7)

- **Level 1**: Consists of casing reamed into a pre-drilled hole, where surface equipment is used to run the casing using rotation and circulation. (Reaming shoe optional). (Figure 1)
- **Level 2:** Involves drilling new footage with a full string of casing and is used in vertical or tangent sections without the need for directional drilling. (Figure 1).
- **Level 3:** Uses the BHA specially designed to be retrieved and reset without pulling the casing out of the hole (POOH), either with smaller jointed pipe, coiled tubing or wire line cable without tripping the whole system into and out of the well with active directional control.
- **Level 4:** The Liner Drilling, by which drilling is done with a drillable casing bit and Directional + Logging BHA + Multi Set Hanger. (Figure 2).
- **Level 5**: New prototype, for faster retrievals systems. Not much information has been published about this level yet.

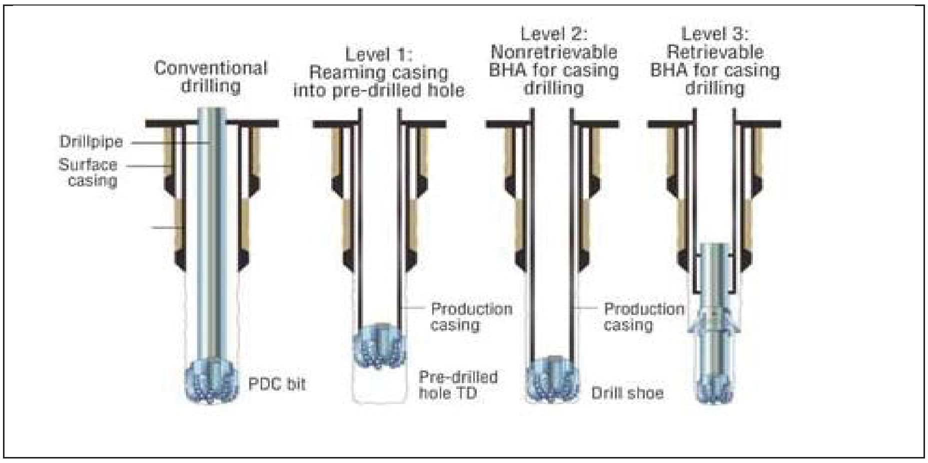


Figure 1: Level 1-3 of Casing Drilling System (2)

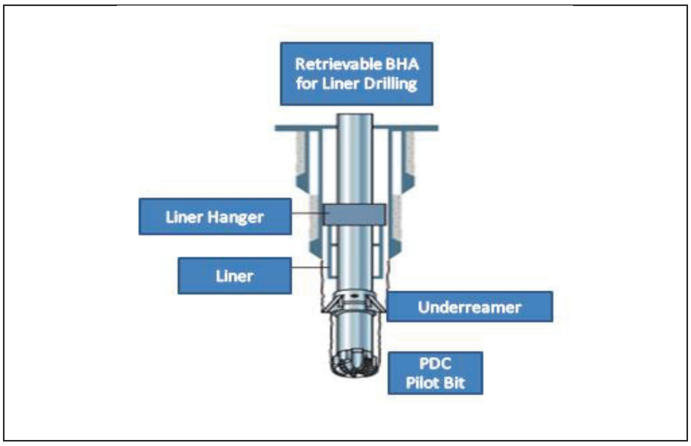


Figure 2: Level 4 Casing Drilling system (3)

2.2. Casing Drilling Process

In the conventional drilling process, as shown by the Figure 1, a drill string which is composed of drill pipe and collars is used to apply axial load and rotary power to the bit (mechanical energy). It provides also a hydraulic conduit for the drilling fluid. The drilling string is tripped out of the hole each time the bit or bottom-hole assembly (BHA) needs to be changed or when the target depth is reached (TD). The casing will then be run to provide a perpetual access to the wellbore. Moreover, after reaching the target depth (TD) and tripping out, wellbore stability and quality issues, such as tight hole, sloughing, mud cake thickening, break out, lost circulation and cuttings settlement might happen and the condition of the wellbore might deteriorate. These hole problems necessitate washing and reaming the casing to the bottom in many cases.

Circulation and reciprocation are the only ways to clean the hole while the casing is being run. If the casing doesn't reach the TD, it's often pulled out and the drill pipe is used for the recondition of the wellbore. A second attempt is then made to run the casing. With the introduction of reamer shoes and tools like the casing drive system (CDS), it is possible to ream and wash to bottom while continuously circulating and conditioning the wellbore. This approach helps the casing to pass through tight spots and work through ledges.

In some cases when the casing is run conventionally, it becomes stuck and must be cemented in place before reaching the TD. After drilling through an interval to the desired depth, the Rig crew removes the drill pipe, leaving the borehole filled with drilling fluid. They lower a casing string to the bottom of the borehole. The mechanical energy and hydraulic energy are provided by the top drive mechanism to the casing string and its pilot bit. The drilling fluid is then circulated down through the string and up through the annulus between casing and wellbore.

2.2.1. Non - Retrievable Drilling with Casing System

The non-retrievable Drilling with Casing (nr DwC) system is based on recent developments in drillable bit technology. The improved performance is achieved with a new series of drill bits that uses polycrystalline diamond compact (PDC) cutting elements mounted on aluminium nose and blades supports. The design gives a premium cutting structure comparable with conventional PDC bits while reducing steel in the drill path by 80%. (1). This steel reduction allows the nr DwC bit to be removed without significant damage to the conventional bit.

The nr DwC technique involves casing drive system (CDS), drillable casing bit and a float collar assembly which are attached to a casing joint where the entire casing string is driven by a surface system. Cementing can be carried out immediately upon reaching the target depth (TD). Conventional drilling assembly is subsequently deployed to drill out the casing bit without the requirement of special drill – out trip.

2.2.1.1. Casing Drive System (CDS)

Figure 3 shows the design of the casing drive system (CDS) used in non-retrievable casing drilling. Its technology can integrate any top drive in its operation. It combines conventional power tongs, bails, elevators, weight compensator, toque-turn/monitoring, and fill up and circulating tools into one system. Safety is improved by remote-control capabilities and reduced personnel and equipment requirements.

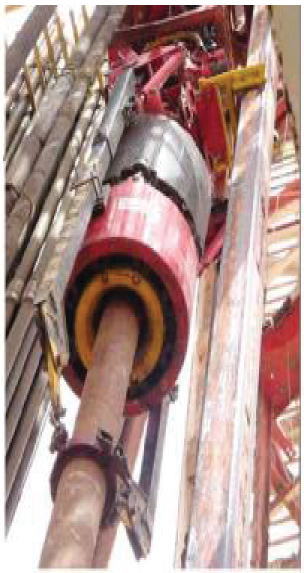


Figure 3: Casing Drive System (CDS) (8)

The heart of the CDS is the TorkDrive tool. With the aid of the rotational power provided by the top drive, the TorkDrive tool presented in Figure 4 and used by Weatherford is capable of circulating, reciprocating and rotating the casing, thereby decreasing any potential of differential sticking or other issues resulting in Non-Productive time (NPT).

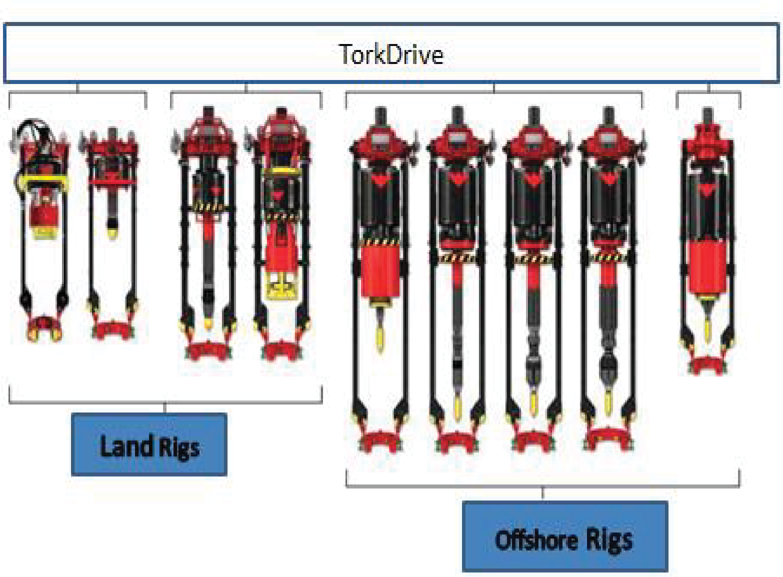


Figure 4: TorkDrive tool (9)

2.2.1.2. Float Collar

The float Collar, shown in Figure 5, is usually attached to a casing joint before being transported to the drilling location. After drilling to the target depth (TD), the cementing can start immediately since the float collar has already been installed within drill string throughout the drilling operation. This operation is the so-called single trip procedure. (11). It can significantly reduce trip time and costs.

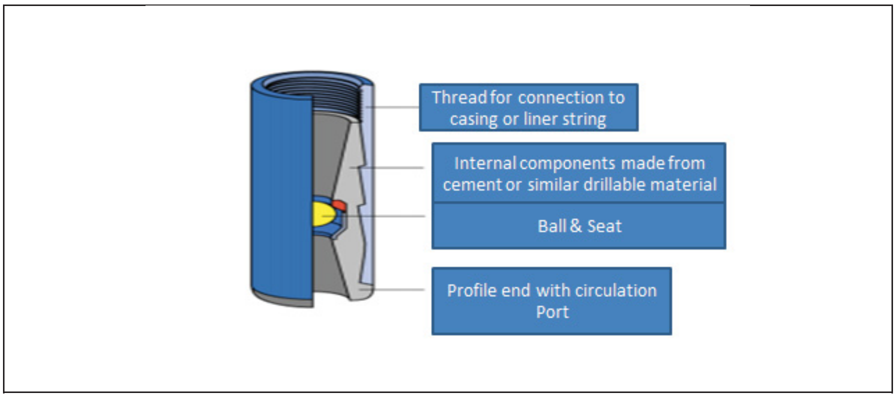


Figure 5: Float Collar (10)

2.2.1.3. Casing Drill Shoe

The casing drill shoe is defined in drilling formation as the bottom of the casing string including the cement around it, or the equipment run at the bottom of the casing string. It can also be seen as a short assembly, typically manufactured from a heavy steel collar and profiled cement interior that is screwed to the bottom of a casing string. The reduced profile helps guide the casing string past any ledges or obstructions that would prevent the string from being correctly located in the wellbore. (12)

The drill shoe is equipped with cutting structure and blades to be ejected abroad once the section target depth (TD) is reached. Therefore, the drill shoe turns to a cementing shoe, allowing the casing to be cemented in place. The cementing shoe and next hole section can then be drilled without interference from the casing drill shoe cutting structure and blades. (1)

2.2.2. Retrievable Drilling with Casing (rDwC) System

The retrievable casing while drilling system generally as seen in Figure 6, generally consists of a special bottom hole assembly (BHA) composed of a pilot bit, under – reamer (UR) and may include tools such as the motorized rotary steerable system (RSS), the positive displacement motor (PDM), a measurement while drilling (MWD), logging while drilling (LWD) and the non – magnetic collars (NMC) needed to perform almost any directional drilling operation that can be conducted with a conventional drill string. These conventional directional tools are suspended below drilling casing shoe. The BHA is attached to a drill lock that fits into a full bore landing sub on the bottom of the casing in such a way that it can be retrieved with wire line unit without needing to trip pipe out of the well. (1)

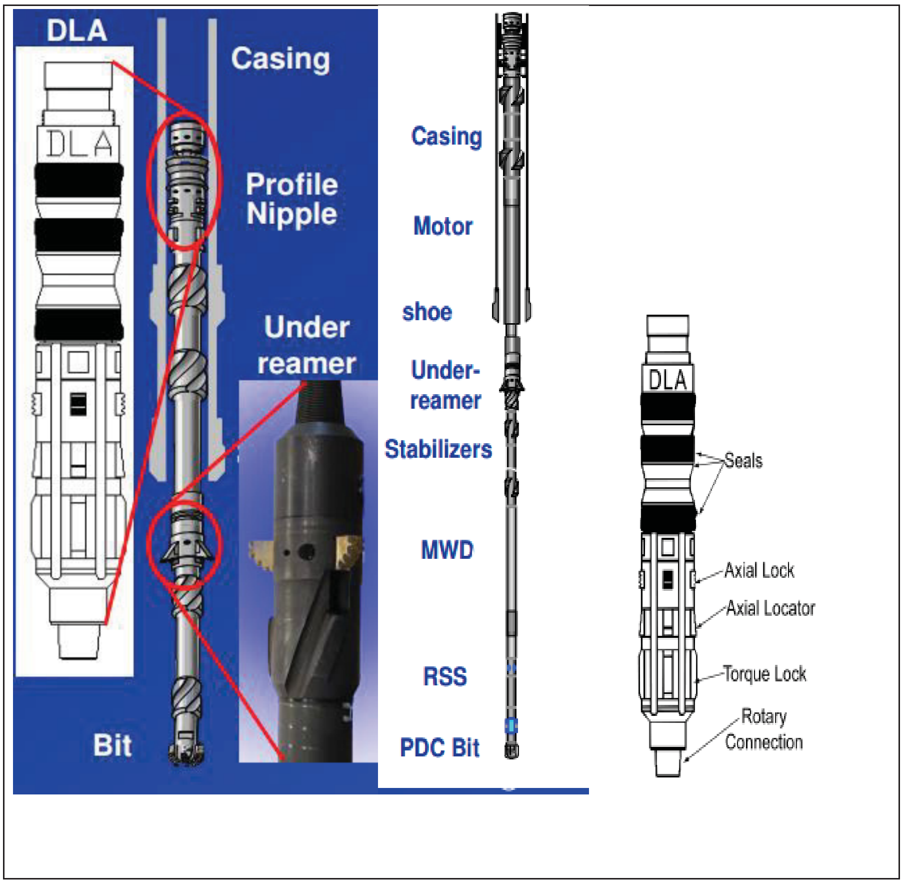


Figure 6: Retrievable casing drilling system (6)

The RSS is a tool designed to drill directionally with continuous rotation from the surface eliminating the need to slide a steerable motor and generally provide a greater rate of penetration (ROP). It also produces a smoother wellbore.

PDM is used to drive the drill bit or other down hole tools during directional drilling or performance drilling applications. As drilling fluid is pumped through the PDM, it converts the hydraulic power of the fluid into mechanical power to cause the bit to rotate. This capability used while drilling is sliding mode, the drill string isn't rotated from the surface. An extra revolution per minute (RPM) is added to the system from the PDM. Stabilizers shown in Figure 6 are added to the BHA to provide vertical control.

Individual joint of the casing are picked up from the V-door with hydraulically activated single joint elevators. Each joint is attached to the top drive with a quick connect assembly that grips the casing without screwing into the top of the casing coupling. The top drive is used to make the connections to the casing string. This quick connect prevents damage to the threads, allows casing connections, minimizes floor activity while making a connection, and increase rig safety. The bits for this retrievable system are chosen for their side cutting ability and stability to reduce vibrations. Under reamer (UR) shall enlarges the well bore past its original drilled size.

The DLA shown in Figure 6 is a tool that connects the drilling assembly to the casing strings and seals the connection hydraulically. It provides also a capability to axially and torsionally lock and un-lock the drilling BHA to the casing and locates itself in the profile nipple without relying on precise wire line measurements, and by passing fluid around the tools for running and retrieving.

A releasing and pulling tool is run on wire line to release the DLA and pull the BHA out of the casing in a single trip for vertical and low angle wells. In the unlikely event that the BHA cannot be pulled on the first attempt, the releasing tool disconnected from the DLA so that the remedial measures can be taken. (4).

2.2.2.1. Casing Drilling & Cementing

The cementing operation consists of injecting cement into the annulus to form a bond between the casing and the formation. The cement bond is notably better on both vertical and horizontal hole sections in which the casing is reciprocated and rotated. Reciprocating and rotating the casing while cementing has been effective in improving the cement quality. As the casing is moving, it distributes the cement evenly, covering the entire circumference of the wellbore. This is especially important in directional and horizontal wells since the casing rests on the bottom side of the well, and if not moved, may result in casing directly contacting wellbore with no cement in between.

A good centralization is also a key for a proper cement job. It provides a good distance between pipe and borehole.
Centralizers are placed along critical sections; to help prevent the casing from sticking while it is lowered into the well. In addition, centralizers keep the casing in the center of the borehole to help to ensure placement of a uniform cement sheath in the annulus between the casing and the borehole well. During DwC operations standard bow spring or welded-body centralizers are not recommended.

This is because there is a possibility to lose them immediately and therefore only special types of centralizers are used. This is, for example the case of SpiraGlider ™ centralizer system used by Weatherford. Weatherford's SpiraGlider centralizer shown by Figure 7 ensures optimal mud displacement for vertical, inclined and horizontal wells. The system is composed of a steel centralizer and two asymmetrically beveled stop collars shaped to minimize running resistance. They have also special rounded blades which reduce casing sliding friction while the stop collar performs as positioning device. The SpiraGlider centralizer heavy – duty (HD) or single-collar (SC) system is recommended when extremely high axial loads are anticipated. They can be used also along with standard centralizers or centralizer substitutes. The stop collar serves as protection tool, producing ramp so that the centralizer can climb over resistances in the wellbore. (13)

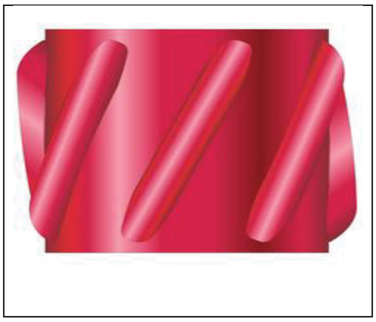


Figure 7: Weatherford's SpiraGlider TM (12)

In the rDwC operation there is no need to place any type of centralizer with an outside diameter (OD) larger than the gauge hole size. Both types of centralizers are desirable where washouts are expected because they provide restoring force to centralize the casing in the hole. A good mud system is essential to minimize the hole washouts. In case of unavoidable washouts, the reduced pipe standoff should be compensated by enforcing other best cementing practices, such as providing good mud properties, pumping rates and spacer design. (1)

In the retrievable system, where the bit has to be replaced before drilling to the next casing point, a full-bore casing access is required in order to pull, run and retrieve BHAs through the inside diameter (ID) of the casing with wire line instead of pulling out the complete casing string by single joints. This makes the use of the floating equipment unsuitable. When installing the floating equipment with casing at the bottom, it will be exposed to high circulation rates for considerable time while drilling the entire hole section. The initial solution to challenge this is to pump a wiper plug ahead of the cement and then latch down cement plug behind the cement, which lands in DLA locking profile. (1). The problem with this operation is the risk of the cement plug being placed improperly. With advances in technology, a pump down float valve was launched and landed in the same profile nipple used by the DLA. The valve serves as conventional float collar to retain the back pressure from the cement job after bumping the cement plugs.

2.3. Casing Drilling Applications.

Initial applications of Drilling with Casing provided an opportunity to develop surface equipment, procedures to effectively handle casing, and equipment to protect the casing and connections while drilling and a robust, reliable system for locking and un-locking the BHA to the casing. (14).

The early applications and subsequent evolution of the system components were basically focused on onshore vertical wells where the cost of learning could be tolerated. The advancement of work diagnosed field applications that would benefit from reducing lost circulation and eliminating problems associated with drilling depleted zones. Despite the fact that these wells have a specific problem addressed by drilling with casing. They were mostly vertical, eliminating a level of complexity in operations.

The rDwC are matured to the point where these operations are routine, and the hardware operates as reliable as rig systems. However, the difficulties remain in applying some technology like Positive Displacement Motor (PDM) to casing directional drilling.

In the meantime, rDwC applications are solving problems in wells at systems in extended-reach directional and horizontal wells (ERD), where the ratio of displacement to true vertical depth (TVD) is relatively high.

As RSS was applied in some fields, improvement of this tool became more durable, and costs went down. It was then applied to higher technically demanding offshore projects.

On the other side, in some onshore applications, it is being used for simply driving the casing to the bottom as the example of Tesco Corporation which is picking up each joint of casing with hydraulically activated single joint elevators attached to the Casing Drive System (CDS) located below the top drive. The CDS system supports the full weight of the casing string and applies torque for both drilling and make-up. Circulation is facilitating without making a threaded connection to the top of the casing. The CDS system includes for both internal and external spear assembly to provide a fluid seal to the pipe and a slip assembly to grip the interior of large casing or the exterior of small casing.

The CDS connects the casing string to a top drive without screwing into the top coupling.

Tesco Corporation CDS also known as casing quick-connect is a casing running and drilling system illustrated in Figure 8.

The use of the CDS speeds up the casing handling operation and prevents damage to the threads by eliminating one make/break cycle. Using the CDS and power slip allows casing connections to be made as fast as drill pipe connections, minimizes floor activity, while making a connection and increase rig floor safety. (7).

Figure 8: Casing Drive System (14)

2.4. Advantages and Disadvantages of Casing Drilling System

2.4.1. Advantages of Casing Drilling System

There are many advantages of drilling with casing rather than drilling with conventional drill string such as: (11) (2) (8).

- **No need to trip drill string therefore the Rig time is** reduced. The casing is already set in the desired depth and ready to be cemented. This eliminates swab and surge pressure in tripping operations.
- **Plastic / smear effect** is a unique feature of Drilling with Casing (DwC) which can stabilize wellbore and mitigate formation damage. This smear effect forces drilling cutting into the formation and reduce the permeability of the formation in the near-wellbore area so it will not let drilling fluid enter the formation.
- **Mud Losses and well control issues** are reduced due to the smear effect the risk to experience mud losses and lost circulation is significantly reduced.
- **Generates more effective borehole cleaning**: DwC has smaller clearance between the casing and the borehole wall which causes high annular velocity and increases the borehole cleaning efficiency. Consequently, it reduces the possibility of stuck pipe.
- Casing Drilling may enable operations where the risk-weighted economics are unattractive for a well drilled conventionally.
- **The system improves personnel safety** by reducing the personnel within the line of fire.
- It eliminates many difficulties that may arise when running a casing.

2.4.2. Disadvantages of Casing Drilling System

The disadvantages for drilling with casing are:

- The technology is only in its infancy (this is valid for Level 3 – Level 2 is now quite state of the art)
- Stuck pipe issues → differential sticking
- They are reduced logging abilities for cased hole work.
- The ability to steer is lacking (Level 2)
- Historically, higher equivalent circulating density (ECD) is considered as a negative aspect of hydraulic design due to higher susceptibility of fracturing the formation and lost circulation.

3. Level 3 (L3) Casing Drilling System.

Even though the casing drilling technology is somewhat common for oil and gas Industry, Level 3 casing drilling remains very special with the fact of having to retrieve the Bottom Hole Assembly (BHA) after drilling the desired depth. This mean leaving an open hole section between the BHA and the last casing string, opening the door for many drilling incidents like wellbore caving.

The Level 3 casing drilling system is a directional casing while drilling (DwC) which provides a unique solution to the lost circulation, recover the expensive directional drilling and guidance tools. It helps also to replace failed equipment before reaching casing point and contributes to quick and cost effective access to the formation below the casing shoe. (8)

The success of any directional drilling depends upon the selection and the design of BHA. Therefore, it is very important to know the components of the BHA and it works. Any failure in BHA design may result in complete failure of the drilling operations. The BHA design objective for directional control is to provide the directional tendency that will match the planned trajectory of the well.

Changes in BHA stiffness, stabilizer placement, hole diameter, hole angle and formation characteristics all affect the directional capability and drilling efficiency of a BHA. By varying stabilizer placement in the drill string, directional drillers can alter side forces acting on the bit and BHA, causing it to increase, maintain or decrease inclination, commonly referred to as building, holding or dropping assembly.

Drilling limitations include rig specifications such as maximum torque and pressure available from surface systems. Geological features such as faults or formation changes need to be carefully considered; for example, very soft formations may limit build rates and formation dip may cause a bit to walk, drift laterally. Local knowledge of drilling behaviour enables the directional driller to derive the correct lead angle needed to intercept the target. (16)

Another evaluation of BHA recently is the utilization of the finite element analysis (FEA) technique. FEA is a mathematical model based on the physical properties of the components and the applied loading. Due to its complexity and a large number of variables involved, FEA allows dynamic, three dimensional analysis of the drill string by dividing the BHA into a large number of discrete elements.

There are two different motor systems that are able to directionally drill with casing. These are the positive displacement motor (PDM) and the motorized rotary steerable system (RSS). The advantages and disadvantages of one over the other will assist in making the decision as to which drilling system is suitable for the well at the hand. Both systems use a wire line retrievable drilling assembly locked into the casing nipple and DLA attached to the bottom of the casing to allow for the retrieval of the BHA and expensive guidance tools used for directional drilling. However, the BHA differs slightly between the both systems.

The motorized RSS tools provide continuous rotation of the drill pipe, minimizing the risk of the pipe becoming stuck or buckled. However, the friction holds the cuttings in suspension, allowing the fluid to create a vortex around the drill string to provide consistent hole-cleaning.

Motorized RSS in directional drilling can be used with larger casing size, but it presents an economic hurdle for less expensive rig operations. (17)

3.1. Available System on the Market

In retrievable L3 rDwC, it's possible to remove BHA in three ways. Either by wire line (slick-line), by drill pipe or by coiled tubing. Although all these three methods could be used, it is important to establish which one will actually be the optimum (to reduce time and costs) for application on the specific rig.

The present day Level 3 Casing while drilling (rDwC) system is offered by oil and gas companies such as Weatherford International and Schlumberger. These companies have a candidate wells for the 9 5/8" intermediate or technical section of the casing, and retrieve the BHA using a conventional drill pipe. During the writing of this thesis, contacts were made with engineers who are currently working for these companies. The aim of these on-going discussions was to obtain relevant information and offset data needed to complete this master thesis. Information collected will be displayed in the following sub-chapters.

3.2. Weatherford Level 3 Casing Drilling System (L3-WTF)

Weatherford (L3 – WTF) shown by Figure 21 is composed of Latch assembly and BHA. (18)

The functional requirements of Weatherford Retrievable rDwC System are:

- Downhole engage-able and release-able coupling for attaching a drilling BHA to the lower end of a casing string for the purpose of drilling with casing.
- Transmission of axial and torsion loads from the casing string to the BHA.
- The BHA may include stabilizers drill collars, MWD, LWD, float sub, mud motor and/or motorized RSS, under-reamer (UR) and bit.

- A Latch may optionally be pre-installed into the profile collar (lower end of casing) at the shop, prior to running in the hole the first time.
- Prior to reaching TD, if the BHA needs to be replaced, the latch assembly and BHA can be retrieved via a retrieval tool on drill pipe, while the casing remains in the hole.
- The latch assembly shown in Figure 9 with a subsequent BHA can be run back down with a running tool (on drill pipe) inside the casing and re-engaged with the profile collar. The drill pipe and running tool is then released from the latch. After the drill pipe is pulled out of the hole (POOH), rDwC operations are resumed to drill ahead.
- Features to have a surface indication (pressure, torque, weight, other) that the latch is in the locked or unlocked position prior to retrieving the drill pipe.

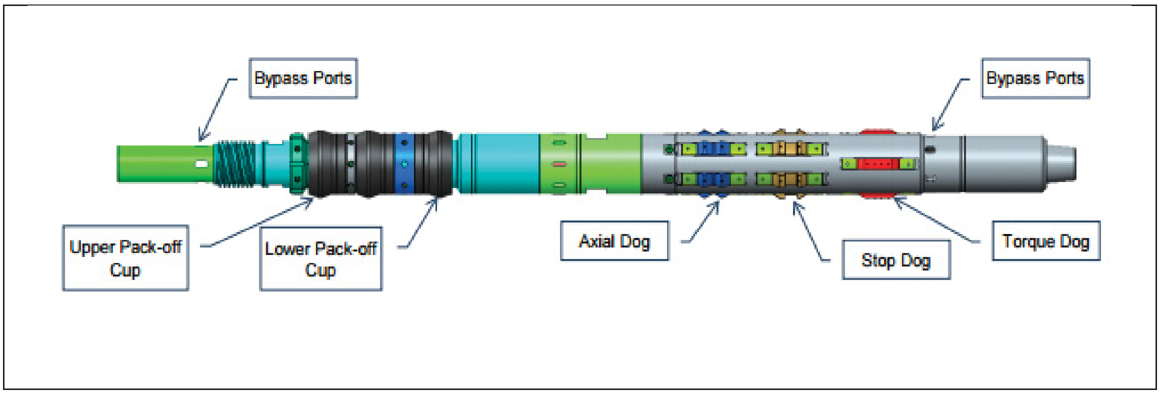


Figure 9: Weatherford Latch Assembly (17)

All latch assembly and BHA components must be retrievable through the ID of the casing. In the Figure 9 it is possible to see also a fluid bypass which prevent surge/swab as the BHA is run and retrieved through the casing (provide a flow path around the packer cups). This bypass must remain closed when the latch is engaged for drilling ahead.

After reaching TD (Target Depth), a retrieval tool can be run on drill pipe to disengage the latch from the profile collar and retrieve the latch and BHA to surface, while the casing remains in the hole. A displaceable un-latching tool may be used to disengage the latch mechanism from the profile collar. The casing may then be urged down over the BHA to cover the rat-hole. A retrieval tool is then run on drill pipe to pull the latch and BHA to surface.

After the latch and BHA are retrieved to surface, cementing is performed. A fluid-conveyed cement plug will be used for the retrievable (rDwC) applications.

Using differential pressure applied from surface, the plug will be pumped down the casing string behind the cement, separating the cement from the displacement fluid. The plug will eventually latch into a dedicated cement plug profile collar to resist u-tubing pressure.

By using a dedicated cement plug profile collar, the operator has more flexibility on positioning the cement plug according to shoe track length requirement. If necessary a second cement plug profile collar can be installed providing redundancy. This redundancy may come from the belter sealing effect if the possibility to have two plugs occurs.

The Weatherford Latch and BHA system is suitable in deviated, horizontal and ERD wells, because it provide limited amount of string weight for engaging and releasing the latch, as well as for coupling and decoupling the drill pipe to the latch.

Burst and collapse rating of profile collar must meet to exceed that of casing. Minimum (same as 53,5# P110).

The technical requirement of the 9 5/8" Weatherford Assembly is shown by the Table 2. The minimum force required to engage and release the latch mechanism is equal to 133 444 N this force may be generated by tension / compression loads for the drilling string, or by hydraulic pressure from the mud pumps up to a maximum of 1500 psi (103 bar).

Casing size	9-5/8"	
Casing weight range	36 to 53,5 ppf	53,57 - 79.61 kg /m
Maximum flow rate	700 gpm	2650 l/min
Maximum drilling differential pressure	3000 psi	207 bar
Latch bottom connection	NC50	
Running / Retrieval tools top connection	NC50	
Torque capacity (between latch & profile collar)	37 800 ft-lbf	51 250 N.m
Maximum set down weight (between latch & profile collar) to accommodate for 3000 psi pressure load	200K lbf	890K N
Tensile capacity (BHA to casing)	250K lbf	1112K N
Tensile capacity (BHA to retrieval tool)	• 148K lbf: safe operating tensile load	658K N
	• 185K lbf :yield load	823K N
Burst capacity of profile collar	10 900 psi	751 bar
Collapse capacity of profile collar	7930 psi	546,37 bar
Operating temperature	30° F to 300° F	-1,11° – 148,89° C
Minimum pass – through diameter	2,50 inch	0,0635 m
Minimum force required to engage the latch mechanism	3000 lbf	13 344 N
Minimum force required to release the latch mechanism	3000 lbf	13 344 N
Design Standard	NS – 1 and NS – 2 compliant	

Table 2 : Technical Requirements of rDwC Weatherford Latch Asembly (18)

The Latch Assembly, together with the Profile Collar described below, provides a means of conveying axial force and torsional force from the top drive to the bit. The maximum pulling force descripts in the Table 2 is 125 tons (250000 lbs) through the Profile Collar and 74 tons (148000 lbs) with the Work String Release Retrievable Device. In the Table 2, the maximum torsional force is equivalent to 50165 N.m (37,000ft-lb). This force is applied at the Torque Dog. The rubber cups are rated to 207 bar (3000 psi). The shape of the Stop Dog ensures smooth passage through couplings. Top and bottom casing connections are NC 50. NC 50 is required to withstand the torsional, axial, and bending loads and also maintenance of adequate pressure integrity.

The components of Weatherford retrievable Drilling while Casing (rDwC) are:

- Profile collar
- Working Release-Retrieval Device (WRRD)
- Hydraulic Locking Device (HLD)
- Hydraulic Release Device (HRD)
- Hydraulic Release Device Launcher (HRDL)
- Latchable Cement Plug (LCP)
- Well Control Device
- RipTide rDwC Drilling Reamer

The primary function of the **Profile Collar** as shown in the Figure 10 is to transmit axial and torsional force to and from the BHA.

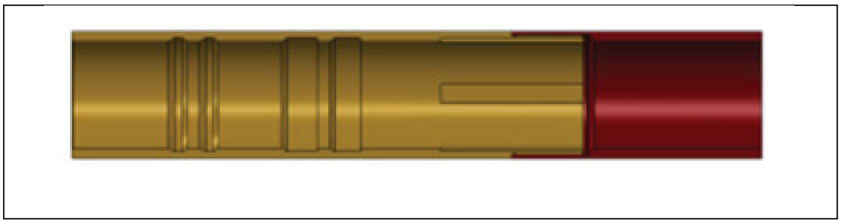


Figure 10: Profile Collar (17)

The Figure 11 displays **the Woking Release-Retrieval Device (WRRD),** which is used to unlock the Latch and retrieve same in one operation. It is deployed with the drill pipe. The Stabilizers placed on the WRRD ensure the device to be centralized when stabbing into the Latch or Hydraulic Release Device (HRD). It has a NC50 Box connection. The maximum yield capacity 92,5 tons (185,000 lbs), (74 tons safe operating tensile load) is described in Table 2.

Figure 11: Working Release Retrieval Device (WRRD) (17)

The WRRD prevents the pulling of a wet string and include picking up and laying down 3-4 casing joints prior to retrieving the BHA. WRRD is intended to ensure that the BHA is pulled up into the reamed hole size to limit chances of getting it stuck.

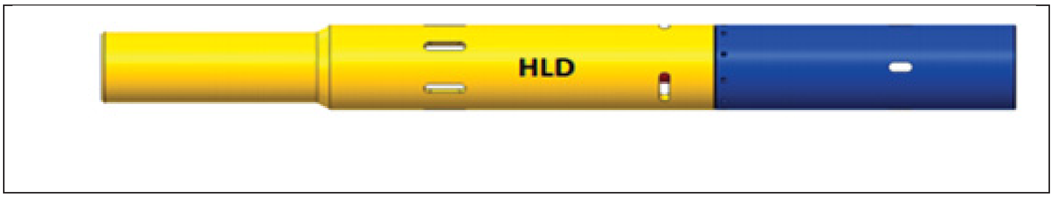


Figure 12: Hydraulic Locking Device (HLD) (17)

The Hydraulic Locking Device (HLD) has for objective to run-in 9 5/8″ Latch and BHA on drill pipe, then the ball drop to lock Latch into Profile Collar and with a Right-hand rotation to release HLD from Latch.

HLD shown in Figure 12 is used to install a replacement BHA at the Profile Collar. After the dogs on the Latch snap into the profile collar, a 2″ ball is dropped. Pressure is up to 1000 psi to shear retaining pins. The subsequent pressure release indicates that the Latch is locked. Once the HLD has completed the locking sequence, pull tests will be performed to confirm the Latch is locked. The

HLD is then released from the Latch by turning it clockwise. After retrieving the Drill pipe rDwC operations can resume.

The Hydraulic Release Device (HRD) presented in Figure 13 is used to unlock the Latch from the Profile Collar without immediately pulling the BHA out of the hole. This allows lowering the rDwC casing to cover the rat hole, or to overshoot a stuck BHA. Once the HRD lands on top of the Latch, it continues pumping to initiate the unlocking sequence. Pump pressure is expected to reach 1000psi immediately, followed by a pressure release. This confirms the Latch is unlocked. After lowering the 9 5/8" casing, the WRRD will be run on drill pipe to engage the top of the HRD, in the similar manner as that to engaging the latch. All components (HRD-latch-BHA) will be pulled out of the hole (POOH).

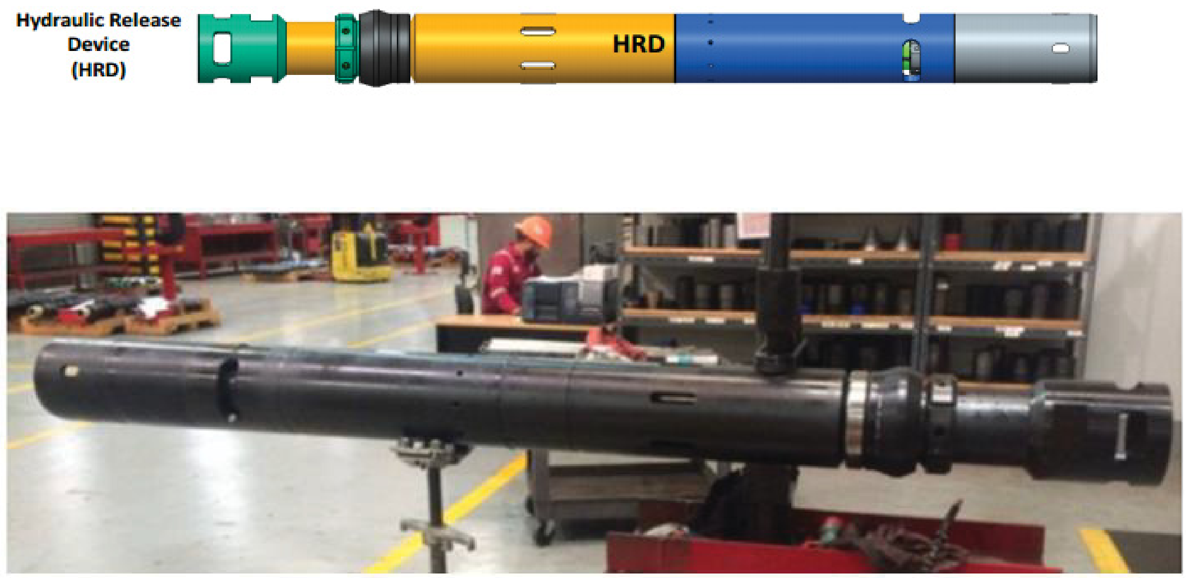


Figure 13: Hydraulic Release Device (HRD) (17)

For the cementing process, Weatherford is using the Cement Plug. The primary functions of the Top Cement Plug are to separate cement from displacement fluid, wipe residual cement off the casing's internal surface and resist U-tubing force. The Figure 14 displays the Latchable Cement Plug (LCP) which will be circulated down the casing string using differential pressure applied from surface and will eventually be latched into a dedicated cement plug profile collar. By using a dedicated cement plug profile collar, the operator has more flexibility on positioning the cement plug according to shoe track length requirement. If necessary a second cement plug profile collar can be installed providing redundancy.

Figure 14: Latchable Cement Plug (LCP) (17)

The aims of the Well Control Device shown in Figure 15 are:

- To provide a means of circulating kill mud during a well control event when drill pipe is positioned inside the casing.
- When a BHA is being run-in or retrieved, drill pipe and a false rotary are used.
- The drill pipe is positioned inside the casing and hung off false rotary.
- It has a side ports (3 × series 95 nozzles) that will always remain open, allowing flow down both the drill pipe and the annulus between the drill pipe and casing.
- It possesses a cup protector that prevents damage to the pack-off cup while stabbing into casing coupling.
- Pack-off cup is tested to 207 bar (3000 psi).

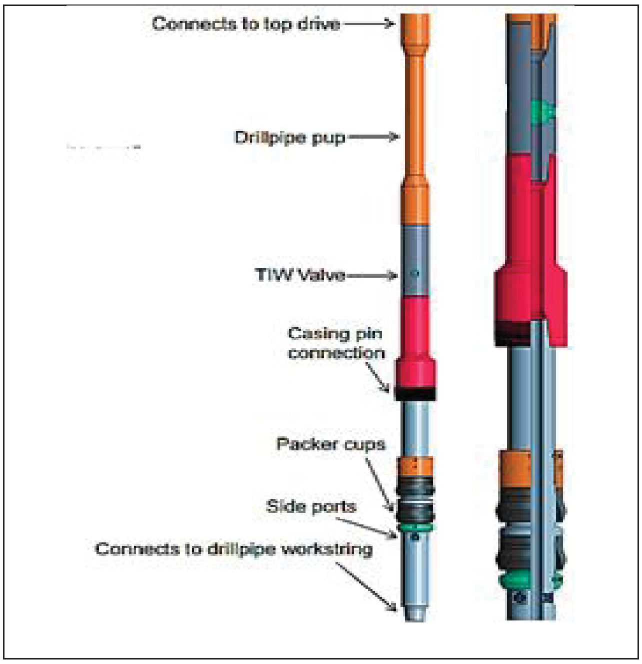


Figure 15: Well Control Device (17)

The last components of Weatherford retrievable Drilling while Casing is the Rip Tide rDwC Drilling Reamer, exhibited in Figure 16, which is a specialized shortened polycrystalline diamond compact (PDC) drilling reamer specifically developed for the rDwC system. It passes through 8-1/2 in drift and opens up to 12-1/4 in diameter and capable of 2650 l/min equivalent to 700 gpm (gallons per minute).

It can furnish 5,000 psi differential pressure between inside and outside of the tool. The drilling reamer opens the wellbore from 8 ½" pilot hole up to 12 ¼" (44% opening ratio). The Rip Tide reamer shown in Figure 16 can be run above a RSS or below a mud motor.

The 9 5/8" × 12 ¼" Casing Reamer can be used for reaming the rat hole in the front of the under reamer. It will not interfere with Rip Tide under reamer (UR) cutter blocks in the event of blocks stuck and is required to pull up against the shoe to close the hole and can be used for back reaming.

Figure 16: Rip Tide rDwC Driling Reamer (17)

After the description of the Weatherford retrievable Drilling while Casing (rDwC), the next step concerns the operational sequence of release and retrieve at Target Depth (TD). Weatherford (WTF) is using 3 sequences and 10 steps to retrieve and release at TD.

In the first sequence is described as following and shown in Figure 17:

First:

A. rDwC to TD
B. The Hydraulic Release Device (HRD) is launched inside the casing ID. Mud pumps are used to force it down the casing bore.

C. The HRD lands on top of the Latch.

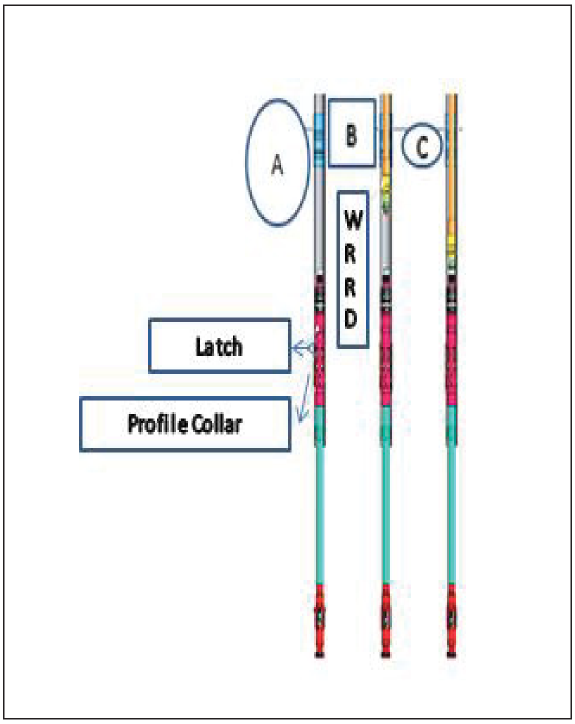


Figure 17: Weatherford first operational Sequence (17)

Second:

D. As seen in Figure 18 below, the pump pressure is used to unlock the Latch Assembly from the Profile Collar. The casing can then be freely manipulated upward, downward or rotated.

E. When it's time to retrieve the BHA, the Working Release-Retrieval Device (WRRD) is tripped in hole on a drill pipe work string.

F. The WRRD engages the top of the HRD.

Figure 18: Weatherford second operational sequence (17)

Finally is the last sequence, pictured in Figure 19 where:

G. The BHA is retrieved on the drill pipe work string.

H. The casing and profile collar remain in the wellbore, ready for cementing.

I. The Latchable Cement Plug (LCP) is then pumped down the casing bore.

J. The LCP latches onto Cement Plug Profile Collar (CPPC). An optional second set of latch profiles can be built into the CPPC for redundancy.

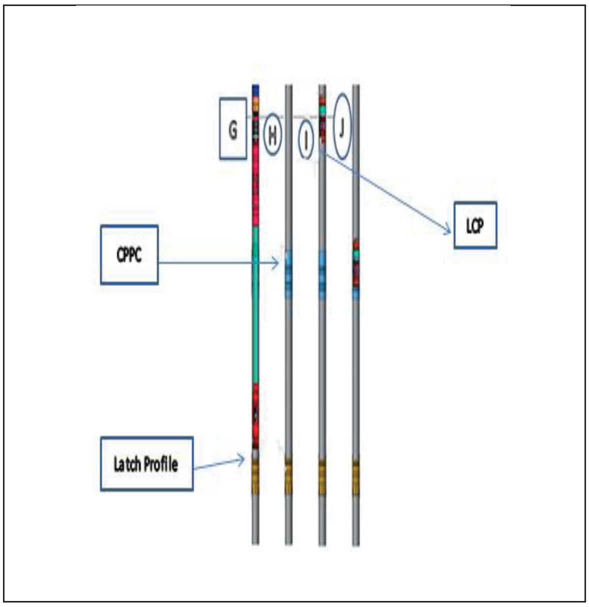


Figure 19: Weatherford last operational sequence (17)

After reaching the TD and retrieve the BHA, cementing operation is performed using one of three methods: (18)

- **Method 1**: A latching top wiper plug is pumped down the casing string behind the cement. This assembly lands in a dedicated plug landing profile collar positioned at a predetermined distance from the casing shoe. It prevents u-tubing. If necessary a second landing collar can be installed to provide redundancy.
- **Method 2**: Cement is pumped down the casing string and pressure is maintained from the surface to prevent u-tubing.
- **Method 3**: Cementing using cement retainer.

The final Weatherford's retrievable tool Drilling while Casing (rDwC) Assembly will look like the Figure 20 below.

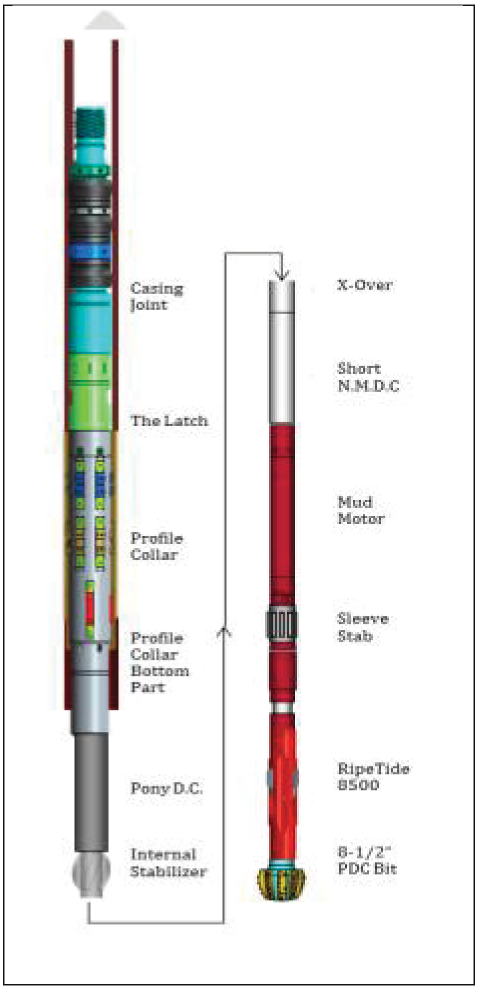


Figure 20: Weatherford Retrievable System (17)

All the steps described in detail above are summarized by this Figure 20 which is combination of all the components listed and described above such as Profile Collar, WRRD, HLD, HRDL, HRD, LCP, and Rip Tide.

The BHA components shown in Table 3 can be set up using either Positive Displacement Motor (PDM) or the motorized Rotary Steerable System (RSS). With a BHA below the casing shoe (15 to 30 m), Weatherford engineers are planning to ream the rat hole at the end using a special casing reamer in order to get the casing at section Target Depth (TD).

	Weatherford retrievable BHA Composition	
Items	RSS	PDM
1	8 ½″ PDC Bit	8 ½″ PDC Bit
2	RSS	8 ½″ x 12 ¼″ Rip Tide Under Reamer
3	Float Sub	6 ¾″ PDM 7830
4	6 ¾″ x 8 ¼″ Non – Mag Stab	Float Sub
5	MWD	6 ¾″ x 8 ¼″ Non – Mag Stab
6	LWD	MWD
7	8 ½″ x 12 ¼″ Rip Tide Under Reamer	LWD
8	8 ½″ Stabilizer	Pony Non – Mag Drill Collar
9	9 5/8″ Latch	8 ½″ Stabilizer
10		9 5/8″ Latch

Table 3: Weatherford retrievable BHA composition (18)

The motorized Rotary Steerable System (RSS) can be used as a conventional motor with an under-reamer (UR) just above the bit in order to have the possibility to get a good directional drilling control with a 6 ¾″ BHA in a 12 ¼″ hole. The Rip Tide DwC under-reamer shown in Table 3 needs to be designed as short as possible to run below directional motor to maximize the deviation force. Nevertheless the bit to bend distance is still considerably longer than without the under-reamer, hence the build rate may not be as high as conventional directional PDM assembly without the under-reamer. Generally, there is a need to evaluate the required build rate.

3.3. Schlumberger Level 3 Casing Drilling System & Case Study

The Schlumberger's Drilling-with-Casing (DwC) service is generally used with a retrievable BHA when the interval must be logged while drilling or drilled directionally. Conveyed on drill pipe, the service works with any BHA and can be used to drill borehole that require multiple bit changes, or for applications that require the motorized rotary steerable systems (RSS) or MLWD tools.

The service includes a drill-lock assembly (DLA) which connects the BHA to the bottom of the casing shoe joint and enables torque and weight to be applied by the casing during drilling. The rig's top drive rotates the casing, and a downhole motor provides additional rotation speed and torque to the BHA and bit.

In between May and June 2014, Schlumberger have used the Level 3 retrievable Casing while drilling system to drill a well called M1, located on the Delta field as shown in Figure 21, at Romanian territory.

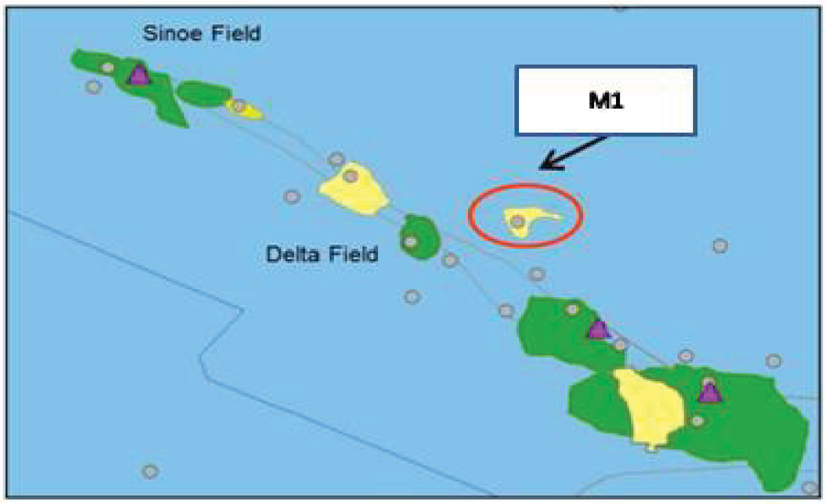


Figure 21: Schlumberger (M1) location (18)

M1 was drilled to determine the presence of moveable hydrocarbons in Eocene /Albian sandstones formations, minimize the flat time, mitigate shallow hazards and minimize flat time. As per drilling program, it is a vertical well with 3 sections cased to surface and 4 ½" contingency liners (3 string design).

The schematic well displayed by Figure 22 utilizes Drilling while Casing Level 2 for the 20" surface casing and Level 3 for the 9 5/8" Intermediate casing section.

M1 retrieved the BHA by using a conventional drill pipe inside the hole. This decision was taken prior to commencing the drilling of the section giving time to rack-back the required drill pipe for the recovery. In some events this may be observed too late and cause down time. In future, this should be coordinated with the rig to establish which method to use in time to be able to be integrated into the drilling program.

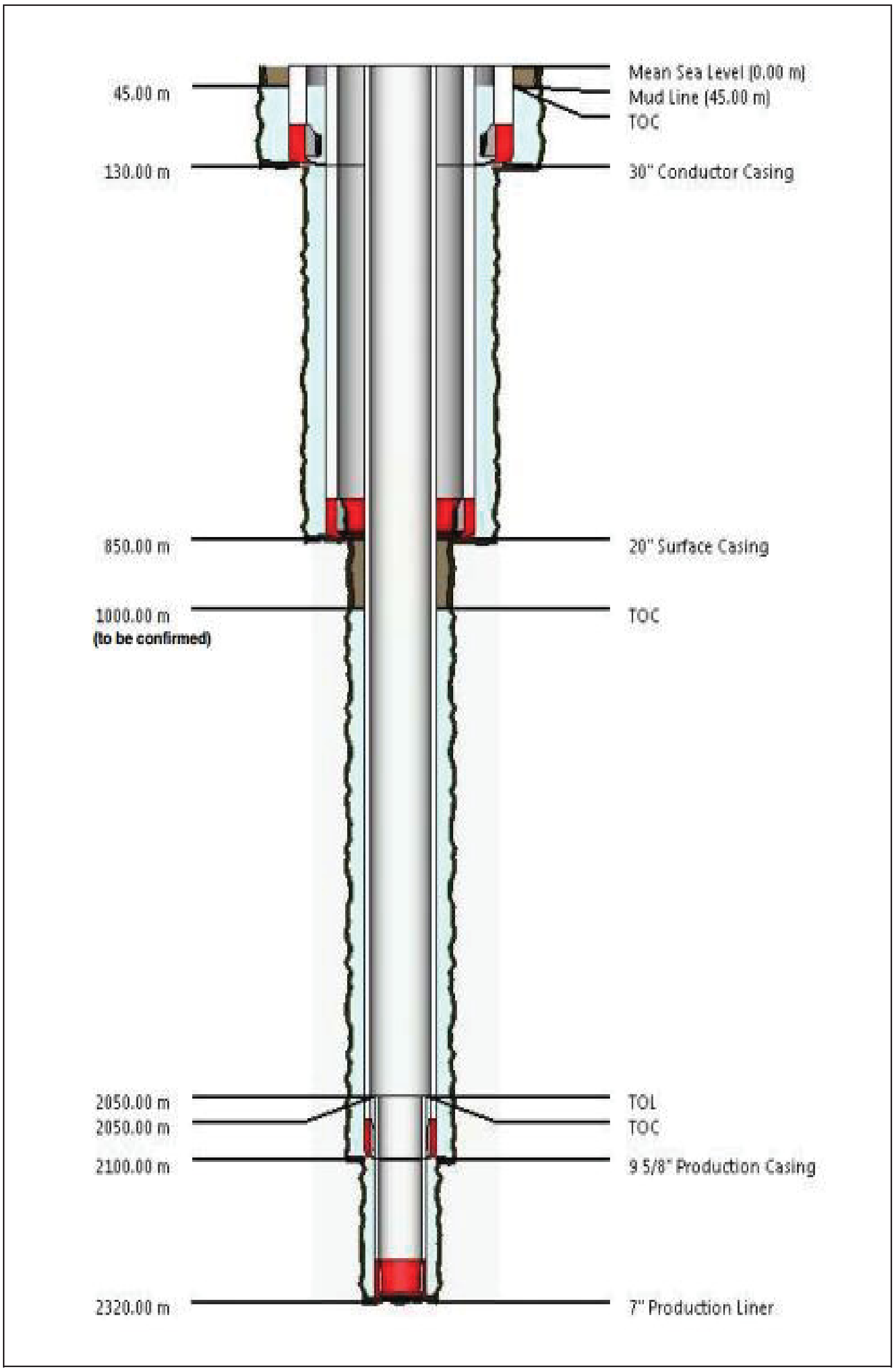


Figure 22: Wellbore schematic of Schlumberger (M1) (18)

3.3.1. Casing objectives

The casing objectives for the 9 5/8” rDwC Level 3 are:

- Isolate over pressured Oligocene shales before drilling ahead in Eocene / Albian reservoir.
- Permit reduction in mud weight when drilling the Eocene / Albian reservoir.
- Permit possible future tie-back to a production platform via the MLS (Mud Line Suspension).

All these Oligocene, Eocene, shales and Albian can be seen in the Figure 23.

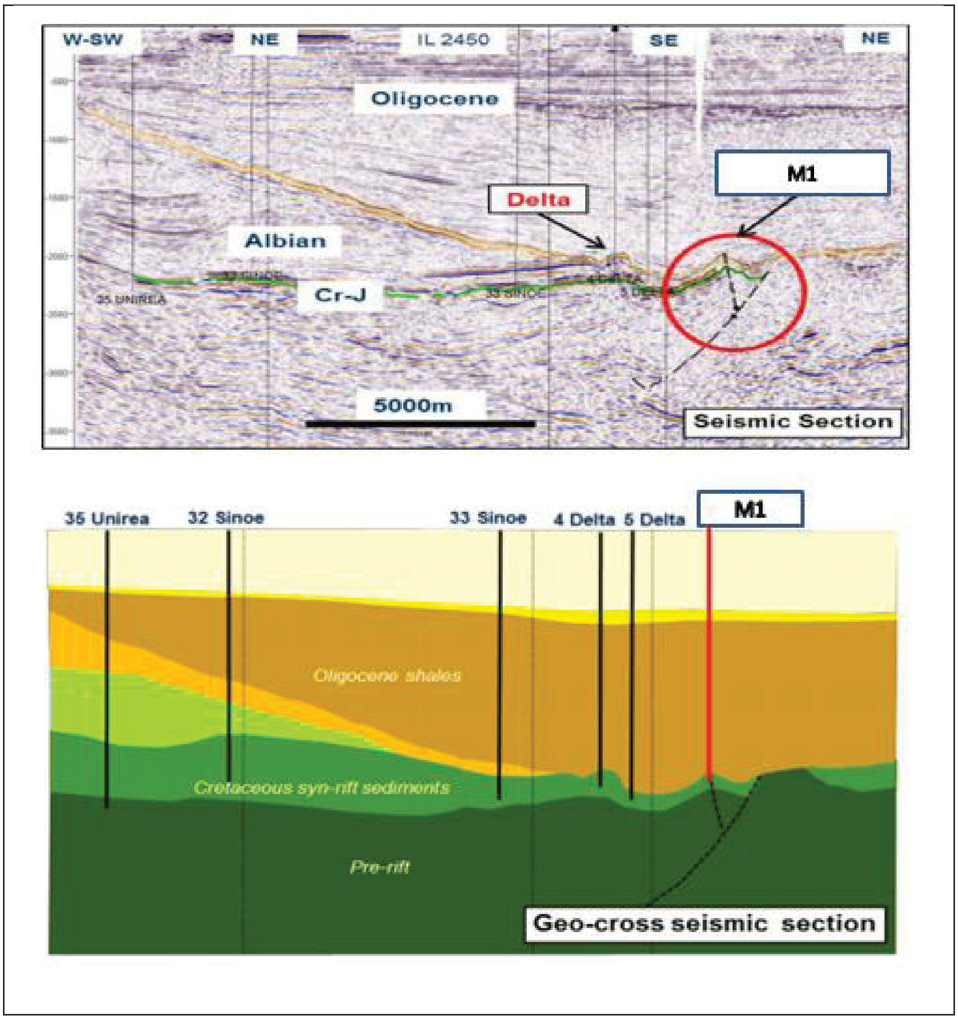


Figure 23: Seismic cross section of Schlumberger (M1) (18)

3.3.2. Drilling-with-Casing (DwC) Operations & BHA Configuration

The TD Direct casing drilling application used by Schlumberger on M1 was a total success paved with the award of one of the longest (1155m) and deepest (2071m) section drilled in Europe and Africa with 9 5/8" casing. Indeed, depth start was 916 m, the TD @2071 m and the running length 1155 m.

Although the directional casing drilling operation was planned to start on the 23 th, the directional BHA was only made-up on the 28 th early morning because of some delays related to the top drive.

The pick-up (P/U) and make up (M/U) of the Schlumberger directional BHA operation was preceded by a safety meeting that started at 04.30 a.m. Once the BHA was made-up, Schlumberger team performed a detailed Safety Meeting with the drilling crew and the rest of the teams involved in the operation. Step by step the procedures for Casing Drive System (CDS), Rig Up(R/U), handling tools shoe joint P/U and M/U were discussed and questions were cleared up.

The Casing shoe joint shown in Figure 24 arrived on the platform pre-assembled with motor, internal tandem stabilizer, drill lock assembly (DLA), casing profile nipple (CPN) and casing guide shoe from the Schlumberger base. Also, there were two non-hard faced (HF) centralizers crimped on the casing shoe joint to help with directional control, casing wear reduction, good cement job on the shoe.

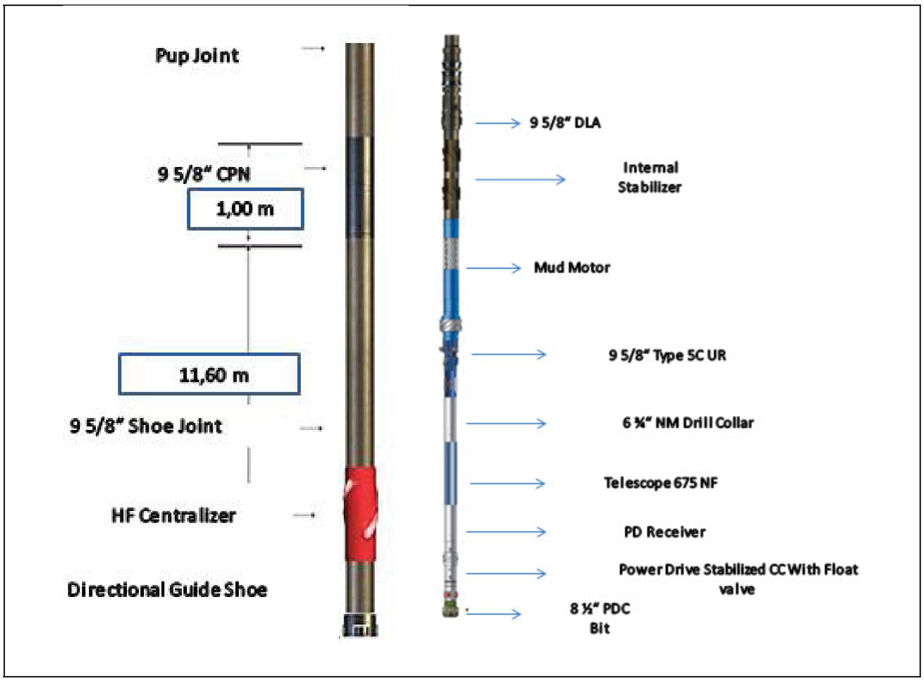


Figure 24: Casing BHA configuration of Schlumberger (M1) (18)

The casing BHA configuration shown in the Figure 24 is described more in details in the Table 4. This table lists the manufacturer for each component to perform the casing directional drilling.

M1 was planned to be vertically drilled to Target Depth (TD) of 2100 m measured depth (MD) but the TD reached was 2070 m MD. Schlumberger performed a clean-out run on the 20″ Conductor pipe with 12 ¼″.

BHA Description	**Manufacturer**
8 ½″ PDC Bit	Baker
Power Drive Stabilized CC **(RSS)**	Schlumberger
Float sub	Schlumberger
Slim Pulse 675- Bat on top	Schlumberger
6 ¾″ NM Pony Collar	Schlumberger
Reamer Borrox 85 8 ½″	Smith
Under Reamer (UR) 12 ¼″	Smith
6 ¾″ 7/8 ML 2.9 HEMIDRIL Inside casing	Nov
8 ½″ Tandem Stabilizer Inside casing	Smith
DLA inside casing	Smith

Table 4: 9 5/8" SLB (M1) BHA Configuration (19)

The motor, logging tools and under-reamer (UR) were successfully tested at the surface prior to run in hole (RIH). The shoe joint was made-up to BHA and the operation continued with the 9 5/8″ casing RIH to 900 m.

At 14:00 pm during casing running the Casing Drive System (CDS) was disconnected from the top drive while making a connection because of a human error. The incident was classified as near miss, no losses were recorded. As a lesson learned for this incident, the Schlumberger's co team supervised the CDS-TD make-up process.

The CDS was then properly attached to the top drive and the 9 5/8” casing running operation was restarted after one hour.

Following the operation stream the 8 ½” directional BHA, together with the 9 5/8” casing, was run in the hole (RIH) and tag bottom (916 m) on the 29 th at 01:10 am. The spud parameters were as follow:

- Flow rate: 1750 l/min= 462 GPM
- Weight on Bit (WOB): 5 t
- RPM (Revolutions per minute): 100 (70 motor + 30 rotary)
- Torque: 6780 N.m (5 klb-ft)
- SPP (Stand Pipe Pressure): 140 bar. = 2030 psi.

An incident occurred while drilling at the depth of 1726m; rain began and the draw works brake started to slip. Thus, it was very difficult to maintain a constant weight on the bit (WOB).

On the 1st June at 06:45 am, after 77 drilling hours the TD was set to 2071 m. the BHA was then retrieved using the Mechanical Release and Pulling Tool (MRPT) run with 5 ½” drill pipe (DP) from the surface.

The MRPT presented in Figure 25 is a tool used to mechanically release and retrieve the BHA from the Casing Profile Nipple (CPN). The MRPT can only be used with drill pipe because weight is needed to mechanically release the DLA.

Figure 25: Mechanical Release Puling Tool (MRPT) (18)

The BHA was Lay Down (L/D), the well was conditioned and the drilling crew proceeded to the cement job.

3.3.3. Schlumberger Cementing Operation

The cementing program for the 9 5/8" rDwC Level 3 section envisage the use of the 8 ½ " hole section. This section is the first section in which hydrocarbons will be encountered. Zonal isolation above the reservoir is crucial. As such a provisional top of cement (TOC) shown in Figure 22, TOC= 1000m is planned (1090m above top reservoir) with an open excess= 30% (based on offset wells and DOM guidance). DOM is the drilling operations manual. The decision were taken to confirm the actual top of cement (TOC), based on gas trends observed whilst drilling the formation Oligocene.

Zonal isolation requires sufficient stand-off (via centralization). As such 1 centralizer / joint must be applied on the shoe track joints and then 1 centralizer / 5 joints above up to 20" shoe. This centralizer configuration is also suitable for the rDwC application.

While drilling this 9 5/8" section, the ROP (rate of penetration) which is about 27 m/hr., was controlled due to lack of cuttings skip availability. Reduction of ROP due to lack of skips is not acceptable. As the estimated total depth of this section was being reached, the ROP was controlled in order to analyses the cuttings sample for better appreciation of the geological limits, especially since it was critical to determine the Oligocene/Eocene limits to completely isolate the Oligocene.

For the mud program, the 9 5/8" casing section will drill the entire Oligocene shale interval [820 – 2090 m]. The Oligocene is predicted to have a pore pressure 1.3 – 1.4 SG (Specific gravity). Most offset wells have encountered some caving (annular / splintered type) when drilling this formation. Although full well bore collapse has never resulted, excessive time has been spent reaming. This indicates the Oligocene pore pressure exceeds the mud weight. As such minimum mud weight of 1.45 SG is planned for the Oligocene shale in M1. In addition a Non Aqueous Fluid (NAF) mud system was to be used. NAF drilling fluid has shown significant improvement in Oligocene shale stability and drilling performance in onshore and offshore Petrom wells.

The application of the rDwC Level 3 to this section will also avoid the need to trip (prior to running the casing) and the associated occurrence of over pulls.

4. Feasibility Study

OMV Austria has decided to make a feasibility study analysis of the L3 rDwC in the Vienna Basin in order to see how successfully the project can be completed accounting for factors that affect it such as those which are economic and technological. Therefore, a conventional well E3 was selected in the Erdpress field where a good potential for the application of retrievable assembly exists. The aim is to reduce the total operating time and costs by eliminating casing runs, wiper trips and increases the rate of penetration (ROP) for the upcoming drilling campaign.

The Technical Feasibility Analysis steps can be summarized as follow:

- Analysis of gathered information from offset wells
- Identification of conventional drilling problems
- Time savings by using rDwC
- Simulations and calculation: torque, buckling and hydraulics
- Retrievable BHA Design
- Personal needed

This technical feasibility of E3 will be compared with Weatherford and the Schlumberger parameters discussed in the previous chapters and once the outcome shows a good well candidate, the economic feasibility study will be performed using the probabilistic approach to determine the profitability and the associated risks.

Based on Weatherford technology and a Schlumberger case study with well M1 described above, a good application of the L3 rDwC required simulations, calculations and analysis were done of the parameters such as torque, buckling, fatigue and hydraulics. These parameters are obtained with the use of modelling software to evaluate drilling dynamics and hydraulics requirement enabling engineers to select a drill string that is capable of performing the specified job.

Torque determines the capacity of the rig to drive the system.

Buckling is used during simulations to provide inferences into casing pipe selection and connection type.

Realistic friction factors are used during the simulations to avoid erroneous results which could lead to obstacles.

4.1. OMV conventional well (E3)

4.1.1. Analysis of E3 gathered information from offset wells:

E3 is part of a 9-well drilling campaign in 2014 and will be the 19 th producing well on the Erdpress Field discovered in 2003. The Erdpress field shown in Figure 26 is a fault bounded three way dip closure, consisting of more than 30 hydrocarbon bearing zones whereof 10 main horizons are considered economical and are in production today. The structure is delimited to the North West (NW) by the North East (NE)- South West (SW) Striking Steinberg Fault.

Figure 26: Erdpress Field (19)

The proposed OMV (E3) well is expected to reach at the end a TD of around 2881 m MD. Three sections are drilled. The wellbore schematic is shown in Figure 27.

The 9 5/8" (12 ¼" hole) casing section is the section in which OMV wants to apply the Level 3 rDwC system. The TD to be reached for this section is 2100 m MD.

The formations drilled for this section of E3 are Pannonian, Sarmatian and Badenian. They are sandstone and clay stone.

4.1.2. E3 9 5/8" Mud System, Directional Profile & BHA Composition

The mud system used for E3 well is a Potassium Carbonate (K2CO3). K2CO3 provides alkanity and potassium ions for water – based fluids (WBM) as a replacement for products that are unsuitable for use in environmentally sensitive areas such as mature field environments.

K2CO3 treatments will depend on application and operational requirements, but it can also be used for reducing calcium hardness while drilling anhydrite, or for treating contaminated mud, by precipitating out calcium carbonate.

K2CO3 is a suitable replacement for Potassium Chloride when providing inhibition for water – based fluids (WBM) in environmentally sensitive areas because it provides an alternative source of inhibitive potassium ions without the high levels of chlorides that can be harmful to the environment.

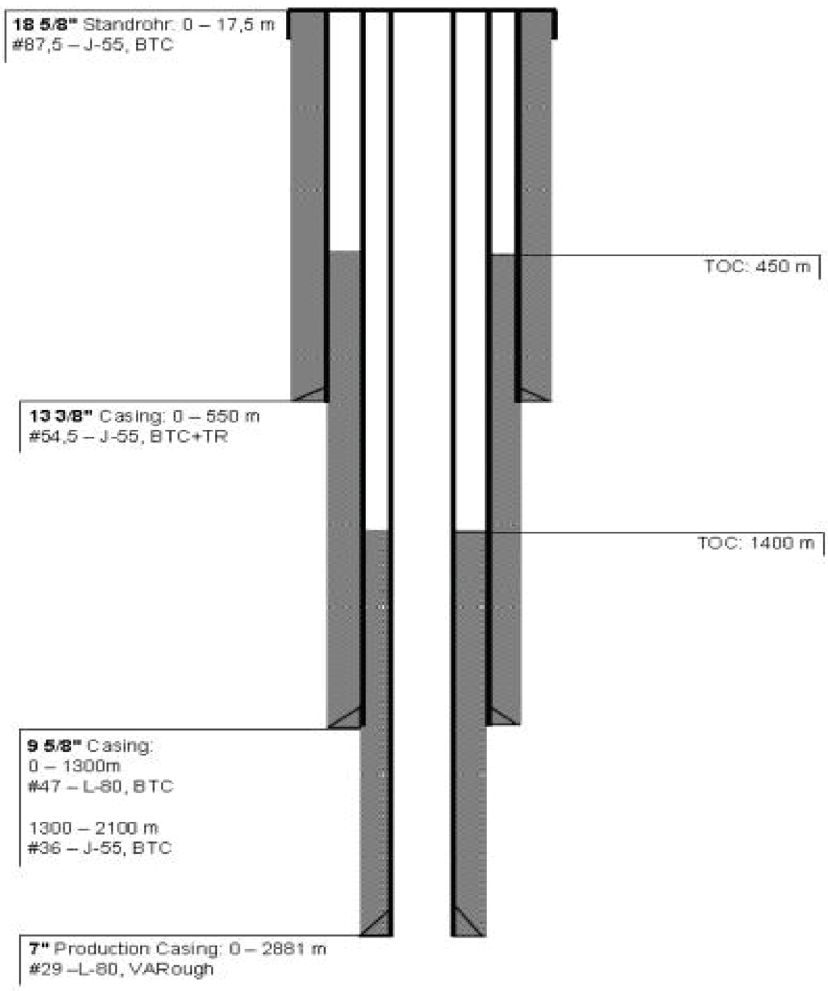


Figure 27: OMV (E3) wellbore schematic (19)

The directional profile:

- Drill 12 ¼" section vertical from 539 m to 1450 m MD (kick off point).
- Build up inclination to 5 deg with dogleg severity (DLS) of 2 deg/100 ft. and 120 deg azimuth at 1525 m MD (measured depth).
- Drill tangent, and then kick off at 1600 m MD.
- Build up inclination to 38,07 deg and turn from 120 deg azimuth to 66,22 deg azimuths with DLS until 2023 m MD.
- Drill tangent to estimate casing shoe at 2100 m MD
- Result: primary target was hit. Section was drilled with an average ROP of 21, 2 m/hr**.**

BHA composition:

- 3 runs
- Type: RSS + MWD
- Components:
    - 12 1/4" PDC Bit
    - Power Drive (PD) 900 X6 BA 12 ¼" Stabilized CC (RSS)
    - PD sub slick W/ Float Valve, PD 900 Float Collar
    - Telescope 825 (MWD)
    - 11 ½" NM (Non Magnetic) Stabilizer + 8 ¼" Flex NMDC
    - PBL Sub + Crossover
    - 8 × 5" HWDP, 6 ½" Accelerator, 2 × 5" HWDP (Heavy Weight Drill Pipe)
- Bit manufacturer & model : Smith + DSX616M-A38
- Bit profile & blades : Matrix HDK body bit & 6
- Nozzles: (3 × 13,3 × 14) / 32"
- Total flow area (TFA): 0, 84 in^2
- Depth In: 539 m MD
- Depth Out: 2054 m MD(@TD)
- Total meters drilled: 1515 m MD

The OMV (E3) well profile is a consequence of restrictions of surface location such as topography, surface and subsurface facilities, environmental and social impact, availability of the land, mine clearing, existence of environmental protected area and location of targets.

Drilling parameters such as flow rate, weight on bit (WOB), RPM, and casing connection which are also capital for the offset wells:

- Flow Rate: 2800 l/min
- RPM: 130
- WOB: 8 t
- The Casing connection:

Diameter	Weight	Grade	Connections
9 5/8″	47#	L80	BTC

Table 5: 9 5/8" OMV (E3) casing connection (20)

4.1.3. Rig Capability & Power Requirements

All OMV drilling campaign have been executed to date using the VDD 200.1 rig which is a land or diesel hydraulic rig supplied by Drilltec.

VDD.200.1 is capable of drilling up to 3500 m. It has an overall height of 33 m considering the substructure. It includes a hydraulic top drive with a maximum torque capacity of (5 498,640 N.m) 40556 lbf.ft with additional maximum ratings of 190 RPM for rotational speed and a maximum standpipe pressure rating of 5000 psi. The hydraulic hoist rig at the draw works is capable of handling a hydraulic horsepower up to 800 hhp (14,108 hsi). The hsi is the hydraulic horsepower per square inch.

VDD.200.1. is equipped with an automatic pipe handling system, which can handle tubular from 2 ½″ to 20 ".

The need to use these parameters such as higher flow rates at higher pressures, use of higher pipe RPM and higher torque and drag forces will also continuously task a rig's output capability. The power may be limited, especially in a back reaming scenario where pick-up, torque and pumps are all operating at/near their limit.

Based on the information taken up from the excel sheet well time break down, the identification of the main conventional problems of a well E3 during conventional drilling operations are shown in Table 6.

Conventional Drilling Problems Identification	**E3 Field**
Wiper Trip	yes
Wash	yes
Ream & Back ream	yes
Total /Partial Losses	yes
Tight Spots	yes

Table 6: OMV (E3) Identification of Conventional Drilling Problems (20)

4.1.4. E3 9 5/8"Cementing Operation

For the cementing operation the sequence is composed of spacer, lead cement and tail cement. The procedure is as follows: The exact slurry composition and volumes will be calculated according to the calliper log. Clean mixing tank and prepare required volume of drill water, take water sample. Prepare all material and additives as per slurry design formula provided by cementing contractor. Pre-mix spacer in mud tanks of drilling contractor or batch mix tank of cementing service.

Tail slurries are designed to enable good cement quality, which are required around the shoe and across the reservoir section for perforation and zonal isolation. The weight of the lead slurry is adapted towards the expected geo-mechanical capability of the formation (e.g. fracture gradient).

Lead cement reduces the hydrostatic pressure during cementation to avoid losses, provide also zonal isolation and form a barrier between the hydrocarbon (HC) bearing horizons and zones above.

4.2. Evaluation of OMV (E3), Weatherford (WTF) & Schlumberger (SLB)

Comparison between E3, WTF and M1 are based on all the parameters listed, simulated and analysed above. It's clear that the comparison remain difficult due to different geological seismic data. WTF and SLB have drilled their wells on different location. Nevertheless, the main objective which was to make an evaluation of the level 3 (L3) of 9 5/8"Casing rDwC has been reached.

Today, WTF uses for 9 5/8" casing section the latch assembly with components such as Profile Collar, Working Release – Retrieval Device (WRRD), Hydraulic Locking Device (HLD), Hydraulic Release Device (HRD), Latchable Cement Plug (LCP) and the RipTide rDwC Drilling Reamer. However, SLB with the TD Direct Technology combines a special BHA composed of DLA, Internal Stabilizers, MWD, CPN and centralizers.

All these components were very important in order to stand out with parameters such as Step-Out (Rat Hole).

The BHA of E3 has clearly too many elements and therefore has a big length. By changing its components with those from WTF and M1 it's clear that the BHA is going to have a smaller length. The components implemented will eliminate E3 problem's encountered during drilling such as wiper trips, wash, ream, back ream and losses. This will reduce drastically the operating time which is the goal of OMV Austria.

4.2.1. Technical Feasibility analysis

Table 7 below summarizes all the important parameters needed in order to make a technical feasibility study of the Level 3 rDwC.

Parameters	OMV (E3)	Weatherford (WTF)	Schlumberger(M1)
Casing Size	9 5 /8″	9 5/8″	9 5/8″
Hole Size	12 ¼″	8 ½″	8 ½″
Target Depth (TD, m)	2054	2100	2071
Bite Type	PDC DSX616M – A38	PDC	QD605
Bit Blades Count	6	6	7
Cutting Structure	16 mm	16 mm	16 mm
BHA Type	PDC Bit + UR + RSS + DLA + Accessories + Casing String	Special Latch Assembly + MWD, LWD, RSS, Mud Motor, UR, Accessories, Casing String	Special TD Direct tool with RSS, MWD, LWD, UR, DLA, CPN,
Step Out (Rat Hole)	37,2 m	22,33 m	24 m
Torque String(ft-lb) /N.m	8000 / 10846	8000 / 10846	8710 / 11809
Max Make Up Torque (ft.lbs) /N.m	10000 / 13558	37800 / 51250	17400 / 23591
Flow Rate (l/min)/GPM	2850 / 752	2650 / 700	1892 / 500
WOB (t)	8	10	8
ROP (m/h)	21,2	30	26,7
Connection Type	BTC	NC 50	TSH Blue
Operating Time (hr.)	168,1	84,2	77
Days	7,00	3,51	3,20
Lithology	Mainly Sandstone, Clay stone and Silty Clay stone.	Sandstone and Clay stone	Calcareous grey black shales with interbeded fine grained sandstones – Silty clay stone and shales possible calcareous limestone
ECD(ppg)	14,92	22,32	17,58
Mud Type	K_2CO_3 (WBM)	OBM	NAF Mud (OBM)
Top TVDss	550 – 2054 m (BGG; LG) (gas)	542 – 2100 m(BGG)	800 – 900 m (water) 900 – 2070 m (Possible oil / gas)

Table 7: Summary of all the parameters

4.2.1.1. Lithology, Bit & UR

The formations drilled considering the lithology are mainly for E3 and WTF dominated by sandstones which implies a medium hard formation. However, M1 contains a high percentage of shales which are a medium soft formation. The rate of penetration (ROP) observed depend on formation hardness and bit choice. The choice of the bit is capital for the formation in order to ensure a high ROP as much as possible. ROP generally shows how fast it is possible to drill, since low ROP is considered an expensive operation. Looking back to the Table 7, the ROP of E3 is equivalent to 21, 2 m/hr., 26, 7 m/hr. for M1 and 30 m/hr for WTF. So in adjusting the formation hardness for the field E3 it will obviously increase the ROP.

The bit used in M1 is a Smith Bit designed to realize high performance while drilling with very good ROP in conjunction with RSS. It reduces axial vibrations. It has been proven in oil and gas industry that the BHA vibration during drilling operations has negative effect on the BHA and its drilling efficiency. Drill string vibrations also cause damage to the drill string and BHA components such as MWD and LWD equipment, and stabilizers. Therefore, the bit information is capital to avoid any BHA failure. The M1 Smith bit is placed on the front of the BHA, hanging below the 9 5/8" casing. This bit come already assembled and ready for field trial with particular specification and has a defined range of operating parameters (RPM=130, WOB=1 – 16 t, Flow rate =300 – 800 GPM and hydraulic horsepower= 1 – 6 hsi). These parameters are given in order to avoid potential hazards such as BHA balling and low ROP.

The bit is also selected after reviewing the best performance from offset wells (number of blades, PDC cutter size). The under reamer (UR)/bit cutting structures must be compatible to enhance the response of the directional BHA. E3 and WTF have in common a model of 6 bladed, 16mm cutting structures, and M1 with 7 bladed and 16 mm of cutting structures are all appropriate bit choice to drill the intermediate 9 5/8" casing section depending again here on the drillability analysis of offset lithology, drilling logs and bit record.

4.2.1.2. Casing Connection Selection

Casing connection selection is subjected to depend on the estimated string torque. This string torque aim is to withstand the torsional, axial and bending loads experienced while drilling. For E3 the estimated string torque required to drill to total depth (TD) is close to 8000 ft-lb which is less than the casing connection (BTC L80) required making up a maximum torque of 10000 ft-lb (API BTC). String torque of M1 (TSH Blue) and WTF (NC 50) are also of values greater equivalent to 87100 ft-lb and 8000 ft-lb. Therefore there is no need to install a multi-lobe torque rings (MLT) in order to increase the maximum drilling torque capacity. For these three fields the string torque required is sufficient to repeat make up, ease rig handling and maintain adequate pressure integrity. Fatigue failure never occurs during the manipulation as well as buckling because casings are not exposed to high stress.

The maximum make-up torque capacity for the land rig VDD.200.1 is up to 40000 ft.-lbs. Looking at the Table 7, the make-up torque for WTF and M1 satisfy this value, therefore no need for rig modification.

4.2.1.3. Directional equipment and BHA Design

Looking at the BHA design, E3 has a great Step Out /Rat hole (37,2 m) which is not beneficial. An improvement in order to set up the BHA and decrease its rat hole is essential. This will allow the wellbore to be drilled in advance. A smaller rat hole below the pay zone is necessary but also depends on logging requirements. For the M1 field for example, SLB (M1) propose to install a pump down unlatch feature which can facilitates a zero rat hole at TD. WTF on the other side with a BHA below the casing shoe (15 to 30 m) is planning to ream this rat hole in order to get the casing at TD. They will use a tool called casing reamer or WTF’s Rat Hole Killer system.

Following the Table 6, with conventional drilling problems like wiper trips, wash, ream, back ream, losses and tight spots the operating time of E3 is still of a great value, up to 168,1 hour which represents 7 days. Latch BHA of WTF on the other side is about 84,2 hour (3,51 days). This is due to the fact that the Latch assembly has fewer elements than M1. The operation is done in much less time than E3.

The TD Direct of SLB (M1) is practically the same, ending with 77 hour (3,21 days). More investigation about the real time to choose is going to be done by using risks analysis and probability assessment in the economic part to evaluate the minimum, maximum and most likely time needed.

The BHA inside the 9 5/8” casing of WTF and M1 is made out of 6 ¾” tools. The RSS point bit along with 8 ½” PDC bit is driven by a mud motor placed and locked inside the casing. The RSS point bit is chosen based on the proved performance in the field. MWD drilling tool is needed to get a good survey. Decoding mud pulse telemetry is a primary concern. The engineering team needs to ensure the appropriate telemetry system is selected for that particular application. The tool telemetry settings must be optimized for decoding.

4.2.1.4. Hydraulics Calculations

Hydraulics calculations are generally carried out to estimate the required rig pumps capacity to drill the objective well. The drilling hydraulics system is a function of the drilling fluid characteristics and its ability to deliver efficient drilling and ensure wellbore integrity and stability. The pump pressure must be capable of giving the flow rate needed to bring the cuttings up and out of the wellbore, as well as overcoming the accumulated pressure losses associated with the surface equipment, the drill string, the bit and the annulus.

The hydraulics analysis is also necessary in order to maintain an equivalent circulating density (ECD) below the expected fracture gradient while achieving adequate hole cleaning. Annular velocity (ft. /min), is another very important variable in the hole cleaning process. As well as flow rate, the RPM, the pressure losses in the annulus and the bit hydraulics power (HHP) are important.

All the parameters listed above should have a specific range in order to satisfy the hydraulics calculations and clean the hole:

- Fracture pressure gradient(F_{PG}) < ECD < pore pressure gradient (P_{PG})
- Annular pressure loss <= 5000 psi
- Average velocity>= 120 ft/min
- Bit HHP>= 2,5

For OMV (E3) the objective was to eliminate the lost circulation problems seen during operating time. So the method consist of balancing the ECD created in the small annulus between the casing and the borehole and still have enough flow rate to clean the hole, generating the required torsional loads from the mud motor and keeping a good hydraulic energy for the bit

For the purpose of this thesis hydraulics calculations were done using a program called Varel**.** It is an excel spread sheet where all calculation could be seen in the Appendix part.

The Table 8 is the summary of all the hydraulics calculations.

Hydraulics Parameters	OMV (E3)	WTF	SLB (M1)
Flow Rate (GPM)	752	700	500
ECD (ppg)	15,31	16,88	15,88
Annular Pressure Loss (psi)	2006,28	1712,96	1340,66
Average Velocity (ft./min)	287,38	267,51	222,82
Bit HHP	2,53	5,52	2,76

Table 8: Summary of Hydraulics calculations

ECD= MW (ppg) + P_{AL}/0,052 x TVD (ft.)

ECD is the equivalent circulating density. It is an important parameter in avoiding kicks and losses, particularly in wells that have a narrow window between the fracture gradient (Fpg) and the pore-pressure gradient (Ppg). MW is the mud weight (ppg), P_{AL} the annular pressure drop in (psi) between the true vertical depth TVD (ft) and the surface (psi).

Annular pressure loss (P_{AL}), average velocity and bit horsepower are all taken from each of the hydraulic well's table. Each well fulfilled the requirements listed above in order to have a good borehole cleaning.

- $H_P < P_{PG} \rightarrow$ Kick
- $F_{PG} < P_{mud} \rightarrow$ Loss circulation

When the mud pressure (Pmud) is so close to the fracture gradient (Fpg), this demonstrates the presence of down hole losses. And if the hydrostatic pressure (Hp) is less than the formation pore pressure (Pp), the appearance of kick is obvious. Losses and kick phenomenon must be avoided in order to operate in safe window, preserving equivalent circulating density (ECD) between the formation pore pressure and the fracture gradient pressure.

Hp is the hydrostatic pressure and Pmud the pressure.

- OMV(E3): 1,15 < ECD < 2,0 SG
- SLB (M1) 1,35 < ECD < 1,98 SG
- WTF: 1,145 < ECD < 2,0 SG

These values of ECD are coming from the mud window of each well displayed by a geologist. Again the operation is carried out in the safe mud window range meaning that no modification or future improvement is needed.

- ECD(E3) = 15,31 ppg (1,83 SG)
- ECD(M1)= 15,88 ppg (2,02 SG)
- ECD(WTF)= 16,88 ppg (2,02 SG)

4.2.1.5. Drilling - Fluids Selection

Drilling fluids types such as water based mud (WBM) and oil based mud (OBM) are selected depending on their use and mud composition. They are designed to provide overbalance, remove cuttings and keep the well open and safe while drilling and tripping until the casing is run and cemented. One major's problem that oil companies are facing in selecting fluids is the occurrence and management of lost circulation.

Lost circulation causes non-productive time (NPT) that includes the cost of rig time and all the services that support the drilling operation. Losing mud into the oil and gas reservoir for example can drastically reduce or eliminate the operator's ability to produce the zone.

If lost circulation zones are anticipated, preventive measures should be taken by treating the mud with loss of circulation materials (LCM). LCM routinely is carried in the active system on many operations in which probable lost circulation zones exist, such as vulgar formations (limestone and chalk).

OMV (E3) used a WBM composed of potassium carbonate (K2CO3)/Polymer mud treated with Glydril while drilling cement. After running in hole (RIH) to 2054 m MD, the borehole was circulated clean and the string was pulled out of hole (POOH). In total, 8,7 m^3 muds were lost to the formation in this section. The losses zones encountered for OMV (E3) well are indicating that the priority for OMV (E3) was to keep the hole full so that the hydrostatic pressure does not fall below formation pressure and allow kick to occur. It may be purposely reduced to stop the loss, as long as sufficient density is maintained to prevent well-control problems. This loss also poses a high risk of differential sticking.

SLB (M1) on the other side composed of Non Aqueous Fluid (NAF) has not experienced such a problem. SLB (M1) asked all mud companies involved in the project to provide sufficient stock of standard effective LCM on their rig location. The LCM asked by M1 combined standard materials other than calcium carbonate fine and medium to deal with seepage, moderate and partial losses.

The advantage of drilling with NAF which is thinner mud(lower rheology) are obvious enough, it's easier to pump so lower pump pressures will be observed and will ensure we are far away from exceeding ECD values. Lower pump pressure and lower yield point (YP) will actually restrain downhole losses. In addition more hydraulic horsepower can be obtained at the bit which will aid to get higher rate of penetration (ROP).

In the SLB (M1) Oligocene shale formation, full wellbore collapse has never resulted; excessive time has been spent in reaming. The decision was taken to use this fluid because of it has superior inhibitive qualities.

The best recommendation would be to take an OBM because of its ability to deal with all the problems mentioned above.

4.2.2. Economic Feasibility Study

Cost estimation and control is a critical activity for well construction, drilling and completion wells. They are varying depending on the project type. In order to forecast cost and duration we choose to use the probabilistic instead of deterministic approach.

The deterministic approach is symbolized by the time we got in the table 7: that is for OMV (E3): 168,1 hours (7 days); SLB (M1): 77 hours (3,2 days) and WTF: 84,2 hours (3,51 days). This time doesn't reflect the probability associated with the outcomes and most likely doesn't represent the range of possible outcomes. The events differs from one well to another. The probabilistic approach on the other hand will provide a non-biased method to capture the range of possible outcomes (the real time). This approach is easy to implement with probability associated with each outcome represented by a distribution curve or histogram. Moreover, this approach makes it possible to evaluate the effect of unexpected events which are typically described with a certain probability to occur in a given time.

When performing probabilistic duration and cost estimation, the operation is broken down into a detailed operation sequence showing the main sub-operations that will be carried out. For each of these sub – operations, input data revealing time and cost are given in the form of probability distributions (triangular, uniform, lognormal, weibull). These distributions are based on historical data or expert judgements or a combination of both.

Triangular and uniform distributions are the most common distribution shapes applied in cost and time forecast (Akins et al. 2005). That is why the decision was taken to use the triangular distributions for the real time estimation.

A triangular distribution is a continuous probability distribution with a probability density function (PDF) shaped like a triangle. It is defined by three values: the minimum value a, the maximum value b, and the peak value c.

Figure 28 shows one example of triangular distribution, where a, b and c position can be seen.

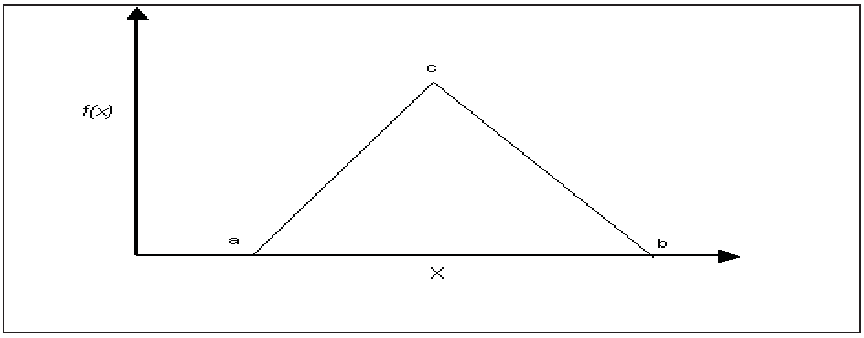


Figure 28: Example of Triangular Distribution (20)

A probability density function (PDF) is defined by the formula:

$$\textbf{PDF} \begin{cases} 0 & \textbf{for } x \leq a \\ \dfrac{2\,(x - a)}{(b - a)\,(c - a)} & \textbf{for } a \leq x < c \\ \dfrac{2}{b - a} & \textbf{for } x = c \\ \dfrac{2\,(b - x)}{(b - a)\,(b - c)} & \textbf{for } c < x \leq b \\ 0 & \textbf{for } b < x \end{cases}$$

From the PDF it is possible to calculate the cumulative distribution function (CDF) of a real-valued random variable X, or just distribution function of X, evaluated at x, the probability that X will take a values less than or equal to x. In this case which is continuous distribution; it gives the area under the probability density function from minus infinity to x. CDF function is defined by the formula:

$$
\text{CDF}
\begin{cases}
0 & \text{for } x \le a, \\
\dfrac{(x-a)^2}{(b-a)(c-a)} & \text{for } a < x \le c \\
1 - \dfrac{(b-x)^2}{(b-a)(b-c)} & \text{for } c < x < b \\
1 & \text{for } b \le x
\end{cases}
$$

An example of CDF function is shown by Figure 29.

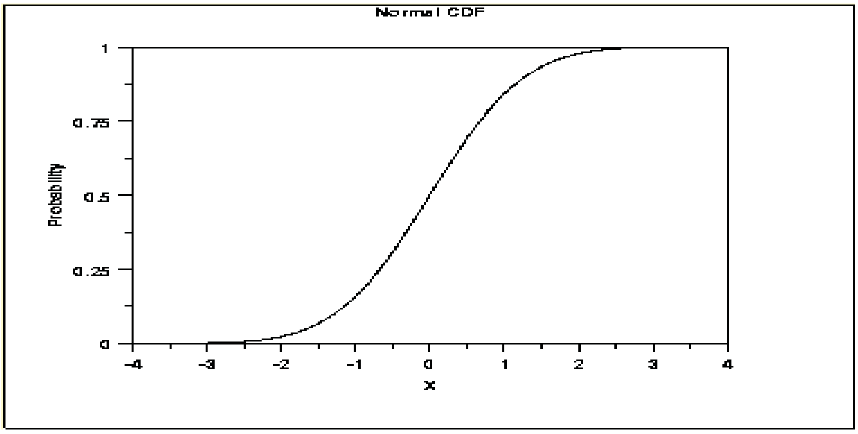


Figure 29: Example of CDF (20)

Cost estimation started by breaking wells OMV (E3), WTF and SLB (M1) in 10 detailed sub operations shown in Table 9 and represented by [$X_1 - X_{10}$]. It was then possible to have for each event the maximum, the minimum and the most likely value in order to perform the probability density function (PDF) and cumulative density function (CDF) calculations. The events with the time associated within each well, can be seen in the Appendix part.

The CDF curve of each sub-operation helps to define a range of uncertainty represented by a probability distribution, P90 (the highest), P50 (the median or most likely) and P10 (a proved or lowest).

X [hr.]	P90	P50	P10
X_1 (HSPJM M/U, P/U, RSS DD BHA)	3,80	3,20	2,53
X_2 (R/U casing drive + handling equipment)	1,37	1,22	1,10
X_3 (RIH with rDwC BHA 9 5/8″ casing to casing shoe)	3,22	2,79	2,35
X_4 (Drill 13 3/8" shoe track, 3m new formation)	2,74	2,30	1,85
X_5 (Continue rDwc drilling 9 5/8″ casing to @TD)	57	51	44,98
X_6 (Circulate B /U)	2,7	2,1	1,49
X_7 (POOH with rDwC BHA)	8,29	6,67	5
X_8 (Break out, L/D BHA 12 ¼″)	2,89	2,4	1,9
X_9 (Cement 9 5/8″ casing)	9,10	8	6,89
X_{10} (BOP stack, Lay down BHA + pre – installation of rDwC assembly)	3,96	3,62	3,27

Table 9: Events and Triangular probability distribution

The next step was to make a random number (801) in the excel sheet in order to calculate the total X hour. This is made by the usage of the look up function to find the corresponding parameters.

Total X [hour] = $X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10}$

The total X hour is going to generate the binominal random variable associated with a binominal experiment consisting of n trials. It will then be possible to define a real minimum (a), most likely(c) and maximum (b) variables which are going to be utilized in combination with the Software Easy

Fit. The Easy Fit software will create the proper CDF and histogram required to find the final probability distribution (P90, P50, and P10).

c= 87

b= 75

a= 102

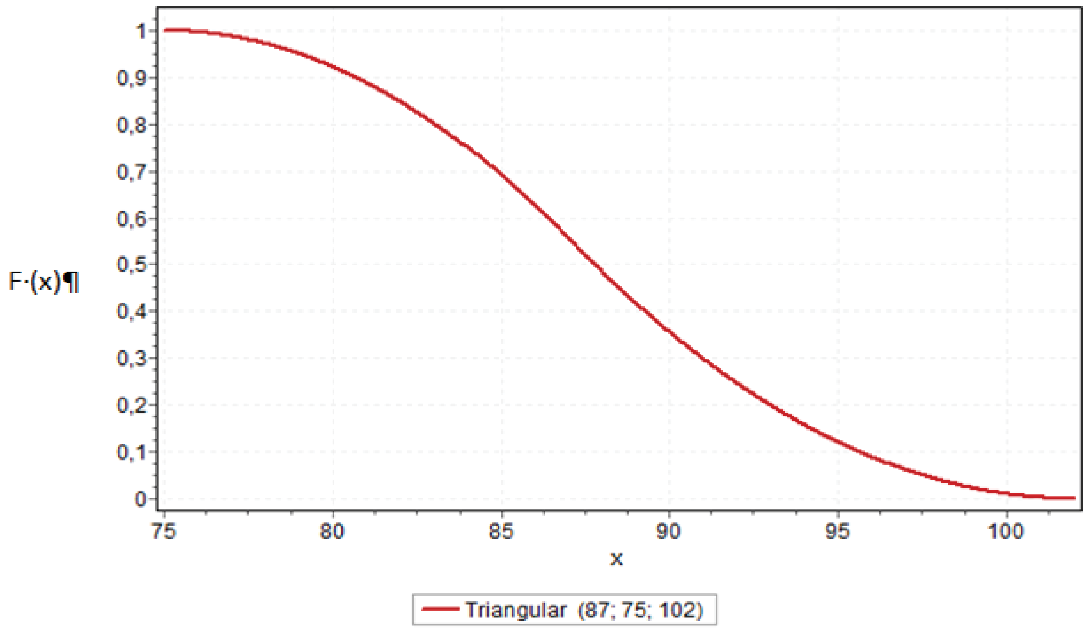


Figure 30: Final Cumulative Density Function (CDF)

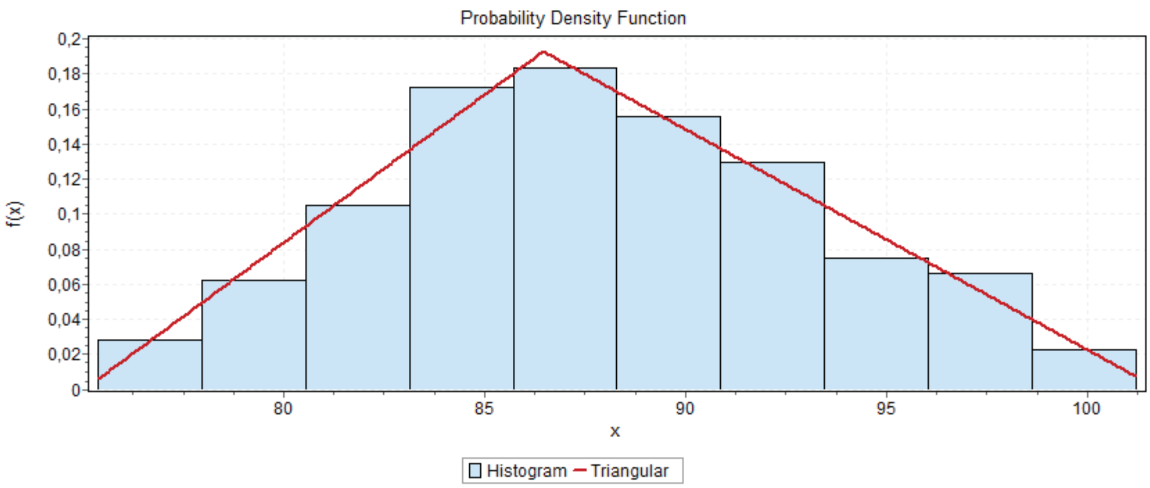


Figure 31: Final Histogram

Finally the real time estimated will be:

- P90= 95,63 hour = 3,98 days
- P50= 87,77 hour= 3,65 days
- P10= 80,69 hour= 3,36 days

There is a lot of discussion going on always in oil industry about what would be the best estimate mean, P50, P90 or P10. However a lot of people would insist that taking the mean is better. This argument is based on the fact that the mean is going to incorporate both the higher and the lower observations which will smooth the differences when added together. This can be compared to the P10, which would potentially give estimates that are over-optimistic, and the P90, a conservative estimate which could potentially leave too much oil, both providing future trends.

It is a common misunderstanding that the P50 is synonym of mean. This is true only if the probability distribution function for the observations were symmetrical. In this case, the mode, mean and P50 would all be the same. So, the best will be to take the mean which work well for symmetrical distributions.

The real time hence will be then **P50 = 87,77 hour= 3,65 days**. Based on this time which will be the real time the cost estimation can be made.

5. Conclusion and Future Recommendations.

5.1. Conclusion

The objectives of this work were to evaluate the viability of using the Level 3 in the 9 5/8″ technical section and determine whether this technology can help to further reduce cost in a mature environment like the Vienna Basin. Although there have not been a large number of studies published, it was possible to understand this technology using a combination of literature review and information collected from experienced drilling personnel working for Schlumberger(SLB) and Weatherford (WTF).

Both companies were involved recently in projects concerning the level 3 casing drilling; Schlumberger with a well called M1 in Romania and Weatherford in Houston.

Based on the information collected, the factors such as harsh drilling environment, torque and drag, casing connection selection, bit and under-reamer (UR), hydraulics, drilling fluids, directional equipment and BHA design were analysed to check the technical feasibility of the Level 3 casing drilling.

It is seen how it is important for a Torque string to have enough load to withstand the rotation, circulation and making up in order to provide a good connection to the casing. Weight on bit (WOB) was also analysed to know the effect of buckling. Stabilizers choice was also of great importance to control the deviation and these provide versatility for various BHA configurations and reduce overall drilling costs. In addition the formation hardness was observed to see the evolution of the penetration rate (ROP).

The results of this technical feasibility study were compared to OMV (E3) conventional well in order to optimize the initial proposed BHA, accomplish the directional plan with tool like the motorized rotary steerable system (RSS), minimize the risks associated to typical hole issues seen such as tight hole and stuck pipe and, finally, reach the planned casing point with the minimum achievable number of bottom hole assembly (BHA) runs.

Hydraulics calculations were made to see if OMV (E3), SLB (M1) and WTF were operating out of the mud window. None were found out of the ECD range. No kick and losses were observed.

The choice of a mud was a key factor for dealing with problems such as high circulation rate and pressure loss. To implement the level 3 casing drilling, the mud chosen should be the one with good potential of hydrogen (PH). The yield point (YP) must be taken in account to reduce well control issues which result from loss in pressure caused by loss circulation. The companies should also always ask to the mud team to provide the lost control material (LCM) to ensure that they are dealing with thinner mud (low rheology) to avoid problem such as seepage, partial downhole and total losses.

The economic feasibility was examined to determine the real time required to achieve the Level 3 rDwC operation. It was based on probability and risk analysis of different events occurring from OMV (E3), Schlumberger (M1) and Weatherford. Therefore a triangular distribution was chosen and the calculations of the probability density function (PDF) and cumulative density function (CDF) were done to define a range of uncertainty represented by a probability distribution P_{10} (lowest), P_{50} (most likely) and P_{90} (the highest). The real time appears then to be P_{50}= 3,65 days.

Due to the confidentiality and the fact Weatherford has postponed the Level 3 rDwC trial since December 2016, because of economic problems; it is not possible at the moment to make cost estimations. The potential savings cannot be seen until the trial is performed.

All these results let to the possibility to implement Schlumberger and Weatherford technology in the Vienna Basin. All the parameters analysed and cited such as BHA, stabilizers, torque and drag must be manipulated carefully.

5.2. Future Recommendations

Drilling with Casing technology is a viable technology for drilling through problematic intervals. As future development projects, several oil and gas companies are exploring the arrival and the commercialization of the Level 4 and Level 5 Casing drilling for liner hanger and advanced retrievable BHA which could be combined with a top drive system.

Another improvement to push the frontiers of casing drilling applications will be the developments of work of Displaceable DrillShoe Tool (DS 3) in order to solve the problems face by operators of getting the drilling assembly out of the way for cementing and drill out operations. The DrillShoe tool (DS 3) displaces cutter blades that can be pushed outward into the annulus using the mud pumps to drive a steel – sheathed aluminium alloy piston. As the tool is at an early stage of development it is planned that constant improvement of the tool, in conjunction with field trials and applications, will further increase its capabilities and push the frontiers of casing drilling applications.

References

1. **Michael Kardos, The American Oil & Gas Reporter, The`" Better Business" Publication Serving** the Exploration / Drilling / Production Industry: Drilling with Casing gains industry acceptance, published in April 2008.
2. **Eric Moellendick, Moji Karimi, TESCO Corporation; "How Casing Drilling Improves Wellbore Stability"** AADE-11-NTCE-64, Houston, Texas, April 12-14, 2011.
3. **Michael Kovac, A. Skulova, Serravallian,"** Sequence Stratigraphy of the Northern Vienna Basin": High Frequency Cycles in the Samartian Sedimentary record. Article issued in December 2008, Geological Carpathians.
4. **Tesco Corporation / Bulletin 3000e** / April 2008 / POD / All rights reserved
5. **Bonar T. H. Marbun, Widiyanto, Yudhistira Adinugratama, and Bramantyo E. Kurnianto**. "Feasibility **Study of Casing While Drilling Application on Geothermal Drilling Operation"** Proceedings, Thirty-Ninety Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, February 24-26, 2014, SGP-TR-202.
6. **Richards Spears**, SPE Distinguished Lecture, Published in 2005-2006.
7. **Dick Ghiselin**, Special Correspondent, Casing Drilling marks a century of progress, issued 10/01/2012.
8. **Kyle S. Graves, SPE, Apache Energy; and Delimar C. Herrera**, SPE, Schlumberger. **" Casing While Drilling Utilizing Rotary Steerable Technology In The Stag Field-Offshore Australia**" SPE Annual Technical Conference and Exhibition held in New Orleans, Louisiana, USA, 30 September – 2 October 2013.
9. **NEDILJKA GAURINA – MEDIMUREC, Casing Drilling Technology**, University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, UDC 622.273.5:622.245.1, Vol 17, Str 19-26, Zagreb. 2005
10. **Tommy Warren, Tesco**, " Casing Drilling effective with retrievable assemblies" Drilling Contractor July/August 2004
11. **T. Warren, Tesco, and B. Lesso, Schlumberger**, "**Casing Drilling Directional Wells**",**OTC 17453,** Offshore Technology Conference held in Houston, TX, USA, 2 – 5 May 2005
12. **Kyle. R. Fontenot, Bill Lesso, R.D (Bob) Stricker, Tommy M. Warren, Using Casing to Drill Directional Wells, Oilfield Review,** ConocoPhilips, Puerto La Cruz, Venezuela, Houston, Texas, USA, Tesco Corporation. Summer 2005.

13. **Bob Tessari, Garret Madell, Tommy Warren**, Oil & Gas Journal**, Drilling with Casing promise major benefits**, issued, 17/05/1999,
14. http://drilleng-group5-directionaldrilling2.wikispaces.com/Directional+Drilling+With+Casing
15. **Andrew Harris**, TESCO Apbu Casing Drilling Review for Asia Pacific Business Unit, Abu Dhabi, December 2010, http://de.slideshare.net/CalHolt/apbu-casing-drilling-review-dec2010
16. Benji George, TESCO CDS Presentation, published on October 2012, http://de.slideshare.net/benji555/cds-ppt-october-2012
17. http://www.tescocorp.com/ProductSales/Casing_Running_Tools/Casing_Drive_System.aspx
18. **Kyle S. Graves, SPE, Apache Energy; and Delimar C. Herrera, SPE**, Schlumberger, SPE 166166, **Casing While Drilling Utilizing Rotary Steerable Technology in the Stag Field-Offshore Australia,** New Orleans, Louisiana, USA, 30 September – 2 October 2013.
19. http://www.slb.com/services/drilling/drilling_services_systems/casing_drilling/directional_casing.aspx?t=2
20. **W.Sackmaier**, OMV; **Ming Zo Tan**, Weatherord International Inc;M. **McGrath, Dr. C. Montoya**; Weatherford Oil Tool GmbH, **"Use of Drilling With Casing Technology to Provide Operational Efficiency in the Vienna Basin**", **SPE 167745**, SPE/EAGE European Unconventional Conference and Exhibition held in Vienna, Austria, 25 – 27 February 2014.
21. A. Kerunwa, C. I. C. Anyadiegwu; Overview of the Advances in Casing Drilling Technology. Petroleum & Coal; ISSN 1337-7027, December 2015.
22. Ming Zo Tan, Steve R, Keith W. Casing bit for harder rock makes drill-out easier, Offshore International E&P Report, 2012, May.
23. Weatherford. Drilling-with-casing (DwC) system. Houston, Texas: Weatherford, DrillShoe Tool, 2005.
24. Oilfield Glossary. Float collar, 2008.
25. Greg G. Rotary Drilling with Casing – Afield proven method of reducing wellbore construction cost. Paper presented at the world Oil 2003.
26. Fontenot K, Highnote J, Warren T, Houtchens B. Casing Drilling Expands in South Texas. Paper SPE/IADC 79862, presented at the SPE/IADC Drilling Conference, 2003, 19-21 February, Amsterdam, The Netherlands.
27. Strickler RD, Solano P. Cementing considerations for Casing While Drilling: Case history. Proceedings at the SPE/IADC Drilling Conference, 2008, 4 – 6 March, Richardson, Texas.
28. Frontenot K, Warren TM, Houtchens. Casing Drilling Proves Successful in South Texas. Paper presented at IADC World Drilling, Madrid, Spain 2002, and 5 – 6 June.

29. Heenan D Advantages of top drive moving to casing running. Drilling contractor, 2003; 22(1):42-43

6. Nomenclature

List of Symbols:

BHA: Bottom Hole Assembly

BTC: Buttress threads Casing

CDS: Casing Drive System

CPN: Casing Profile Nipple

DLA: Drill Lock Assembly

DLS: Dogleg Severity

DOM: Drilling operations manual

rDwC: Drilling while Casing

ECD: Equivalent Circulating Density

ERD: Extended Reach Directional well

HSE: Health Safety and Environment

HWDP: Heavy Weight Drill Pipe

KOP: Kick-Off Point

L/D: Lay Down

LWD: Logging While Drilling

M/U: Make Up

MRPT: Mechanical Release and Pulling Tool

MWD: Measurement While Drilling

NMDC: Non-Magnetic Drill Collars

NPT: Non Productive Time

PDC: Polycrystalline Diamonds Compacts

PDM: Positive Displacement Motor

POOH: Pull Out of Hole

P/U: Pick Up

RIH: Run in Hole

ROP: Rate of Penetration

RPM: Revolution per Minute

RSS: Rotary Steerable System

R/U: Rig Up

SPP: Stand Pipe Pressure

TD: Target Depth

TFA: Total Flow Area

TOC: Top of Cement

TVD: True Vertical Depth

UR: Under reamer

WBM: Water Based Mud

WOB: Weight on Bit

WOC: Weight on Cement

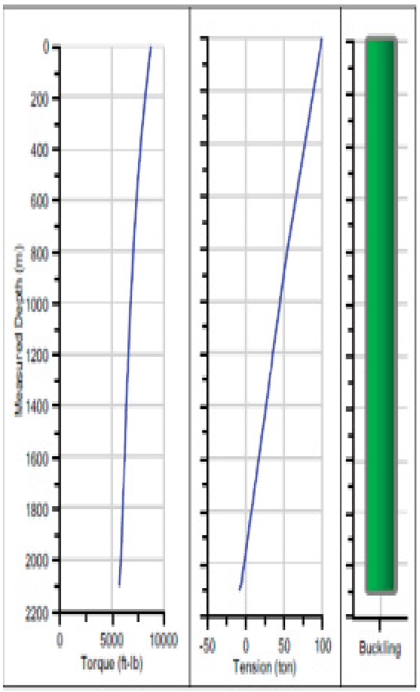
7. SI Metric Conversion Factors

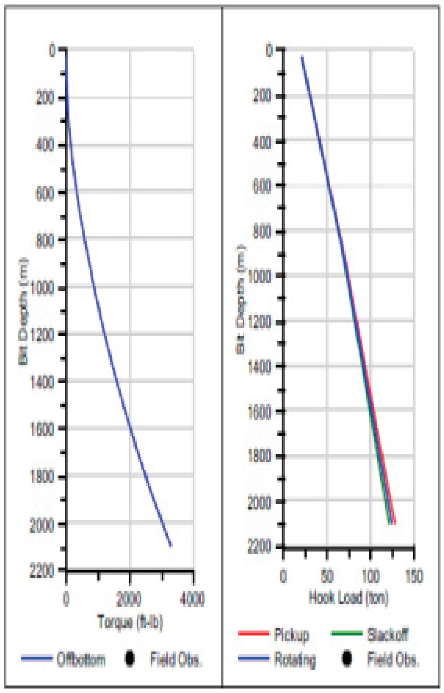
Multiply	by	To get
inches	0,0254	m (meters)
feet	0,304	m
ppf	1,488	Kg/m
gpm	6×10^{-4}	m^3/s
meters	3,29	feet (ft)
psf	47,9	Pa (Pascals)
psf	4,88	Kg/m^2
psi	703	Kg/m^2
psi	6,89	KPa
pcf	16	Kg/m^3
psf/ft	0,157	KPa/m
in - lbs	0,113	Nm
ft - lbs	1,36	Nm
pounds	4,45	N
kips	4,45	kN
lbs per linear ft	1,49	Kg/m
Pascals	1	N/m^2
°F (Faraday)	(°F – 32) × 5/9	°C (Celsius)

8. Appendix

8.1. Appendix A: Schlumberger (M1)

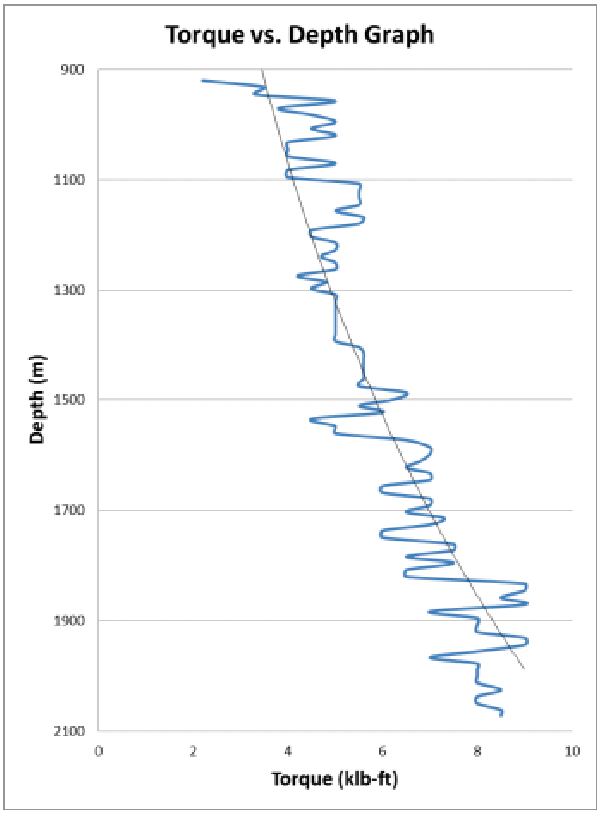
- Torque and Drag Analysis for 9 5/8″ section of M1:





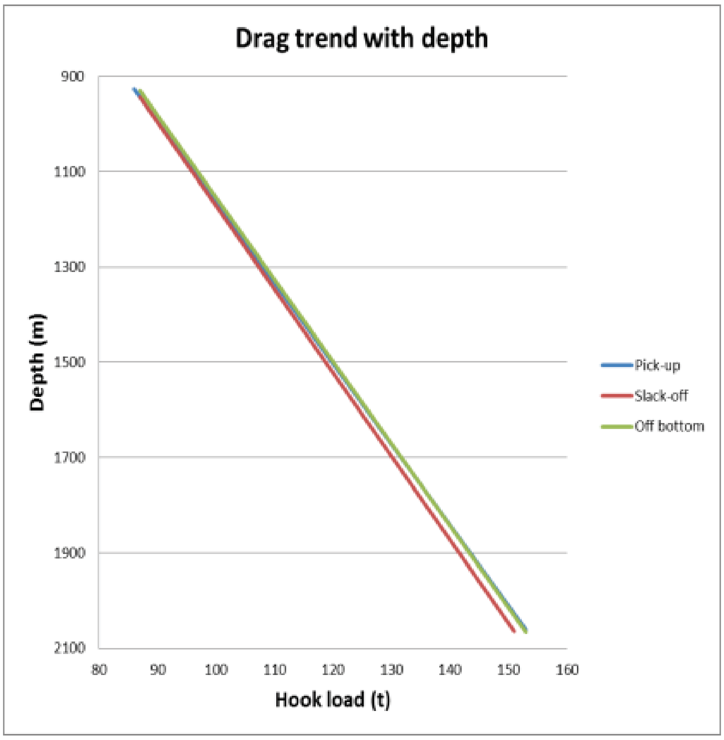
Buckling Legend	
	No Buckling
	Sinusoidal Buckling
	Helical Buckling

▪ Torque trend graph result for 9 5/8″ section



We can see looking at this graph that with the software we reached 2070 m MD.

▪ Drag trend graph for 9 5/8″ section



Looking at the Drag trend with depth after the simulation in the software we can see three lines with different colours. Blue colour determines the Pick Up (P/U), Red where a driller will slack off on the brake to put additional weight on the bit (WOB). It's also the weight reading when the pipe is entering the well. Finally it is compared to the Pick Up weight to estimate the friction. The last colour green displays by the computer the Rotating off Bottom (ROffB) where pipe rotates without any axial movement such as rate of penetration (ROP) or tripping. There is no weight on Bit or Torque on Bit (TOB) because the bit is not engaged with formation.

- **Smith Bits**: Technical Proposal

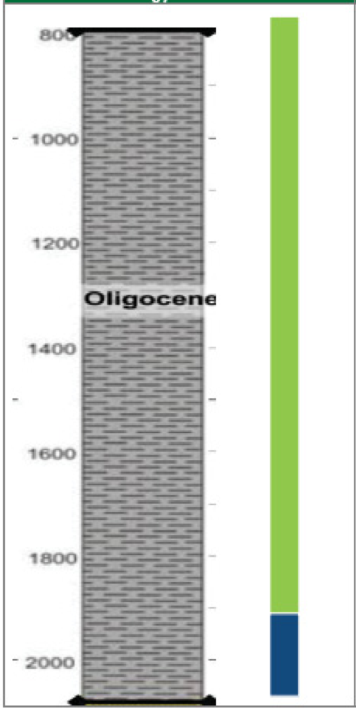
SMITH BITS
A Schlumberger Company

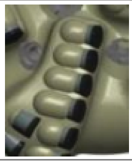
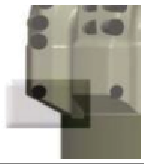
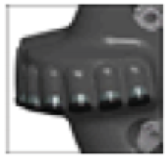
8 ½ " – 12 ¼" Section

General Information	
Depth In	+830m
Depth Out.	+/-2100 m
Interval	+/-1270 m
Lithology	Oligocene

Potential Drilling Hazards
• Bit and BHA (PDM+MWD) baling
• Low ROP and axial vibration

Mitigations
• Use proper mud additives and control solids content by SCE, Clean the hole properly , use adequate Flow Rate
• Use adequate drilling parameters, RPM & WOB to avoid vibration in CWD Level 3 tools.

Potential Lithology	Code	Bit Selection
	PDC MT	Smith Bits Directional bits consistently deliver superior performance in directional applications with both push-the-bit and point-the-bit rotary steerable systems. The MDSi716LUBPX Bits are designed to realize high performance while drilling with very good ROP in conjunction with PDM or RSS tools. As back-up , we recommend alternative for this bit, MDSi616LBPX, PDC bits are designed to drill in various formations with a very good performance and reducing the vibrations while drilling with PDM or RSS without sacrificing ROP.

Key Features	
L Feature - Low Exposure (MDOC-Managed Depth of Cut) Feature: Cutter backing is raised so that the max depth of cut is limited by the engagement of the blade tops into the formation. Advantage: Reduces cutter loading and limits the torque that bit can produce which is useful for directional applications. Benefit: Minimizes cutter breakage and extends bit life.	
PX Feature - Diamond-Enhanced Gauge Protection Feature: Diamond-Enhanced gauge protection. Advantage: Thermally stable polycrystalline (TSP) diamonds provide extra protection to the gauge. Benefit: In gauge hole and longer bit life; longer drilling intervals without the need for tripping.	
B Feature - Backreaming Cutters Feature: Backreaming Cutters Advantage: Strategic placement of cutters on the upside of each blade, to allow backreaming in tight spots, reduces the potential of "bit sticking" while pulling out of the hole. Benefit: Allows a degree of backreaming, sufficient to condition a borehole without major risk of gauge pad wear.	
Limited Torque-Blade tops are raised so that the maximum depth of cut is limited by the engagement of the blade tops into the formation. This limits the torque that the bit can produce which is very useful for directional applications which utilize a steerable motor assembly.	

These bits are achieving superior performance in challenging applications all over the world.

- Drilling Fluids Program of 9 5/8″ Casing Section (Marina 1):

  Before starting the activity with oil base mud check and change the rubber parts if they are damaged. Pits system has to be design in ode to mix separately brine, NAF MUD, store NAF MUD and oil base. Moreover all pits have to be cover.

  Calculation of the composition of the mud is prepared on the basis of the O/W ratio and the density required. The build-up of the system is done under maximum shear in order to enable better emulsion.

  The 9 5/8″ section is drilled through the Oligocene with NAF MUD system to prevent hole instability. In order to ensure optimum rheology characteristics an O/W ratio 80/20 is recommended

Mud Parameters	U. M	Interval
Bit diameter	in	8 ½"
Interval (MD)	m - m	830 - 2100
Footage	m	1270
Type of Fluid		NAF
Density	kg/dm^3	1, 45
Marsh Viscosity	sec/l	60 - 65
PV	cP	33 - 46
Yield Point	$lb/100\ ft^2$	20 - 25
Gel 10 sec	$lb/100\ ft^2$	8 -12
Gel 10 min	$lb/100\ ft^2$	12 - 20
API Filtrate	$cm^3/30$ min	/
PH		/
Ca++	mg/l	/
MBT	Kg/m^3	/
LGS	% Vol	‹ 6
O/W		80 / 20
WPS		200000
Pom		2 - 3
Lime Excess		5 - 10
Electrical Stability		› 600
Filtrate HTHP		4 - 5

The AVOIL system use guarantee a great stability in the most prohibitive condition of use such as high temperature, high deviation angle, presence of soluble salts, water contamination from the formation, etc.

➢ M1 Hydraulics Calculations: Software VareL (Imperial)

VAREL
UK LIMITED

RECOMMENDED BIT: QD605

COMPANY:	SLB	FIELD:	
WELL NAME:	M1	RIG:	
FORMATION:	Shales w/Sandstones	AREA:	

BIT RUN DETAILS		PUMP DETAILS		DRILLING FLUID		
HOLE SIZE:	8,50	TYPE SURFACE CONNECTION:	4	TYPE (WATER=1, OIL=2, POLYMER =3):		2
					DEPTH IN	DEPTH OUT
DEPTH IN:	3013	MAX OPERATING PRESSURE:	2500			
DEPTH OUT:	6812	LINER SIZE:	6	MUD WEIGHT:	12,1	12,9
				PLASTIC VISC:	33,0	46,0
LWD / MWD / MOTOR DEATAILS				YIELD POINT:	20,0	25,0
TYPE:	Motor	PRESSURE DIFFERENTIAL:	870			

BHA DETAILS	O.D.	WEIGHT	EQUIV. I.D	LENGTH	CASING	I.D.	LENGTH	NOZZLES	
TOP DRILL PIPE:	4,800		4,000	3013	TOP CASING 1:	8,350	3012	LATERAL JET 1:	12
BOTTOM DRILL PIPE:					CASING / OH 2:	8,500	1	LATERAL JET 2:	12
TOP HEAVY WEIGHT:	5,000		3,000		CASING / OH 3:			DOWN JET 1:	12
BOTTOM HEAVY WEIGHT:					CASING / OH 4:			DOWN JET 2:	13
TOP DRILL COLLARS:	8,250		2,830		CASING / OH 5:			DOWN JET 3:	13

	O.D.	WEIGHT	QUIV. I.I	LENGTH		I.D.	LENGTH		
TOP DRILL PIPE:	4,8000	0,00	4,0000	6812	TOP CASING 1:	8,3500	3012	LATERAL JET 1:	12
BOTTOM DRILL PIPE:		0,00			CASING / OH 2:	8,5000	3800	LATERAL JET 2:	12
TOP HEAVY WEIGHT:	5,0000	0,00	3,0000	0	CASING / OH 3:	0,0000	0	DOWN JET 1:	12
BOTTOM HEAVY WEIGHT:		0,00			CASING / OH 4:	0,0000	0	DOWN JET 2:	13
TOP DRILL COLLARS:	8,2500		2,8300	0	CASING / OH 5:	0,0000	0	DOWN JET 3:	13
BOTTOM DRILL COLLARS:	0,0000	0,00	0,0000	0	CASING / OH 6:	0,0000	0	DOWN JET 4:	13
								T F A :	**0,720**

DEPTH IN									
FLOW RATE:	500,00	520,00	540,00	560,00	580,00	600,00	620,00	640,00	660,00
TOTAL PRESSURE DROP FOR SYSTEM (LESS BIT):	1340,66	1376,97	1414,55	1453,41	1493,52	1534,90	1577,54	1621,42	1666,56
AVAILABLE PRESSURE FOR BIT (PSI):	1159,34	1123,03	1085,45	1046,59	1006,48	965,10	922,46	878,58	833,44
PRESSURE DROP ACROSS BIT (PSI):	536,97	580,79	626,32	673,58	722,55	773,24	825,65	879,78	935,62
TOTAL PRESSURE EXPENDITURE FOR SYSTEM (PSI):	1877,63	1957,76	2040,88	2126,98	2216,07	2308,14	2403,19	2501,20	2602,18
STANDPIPE PRESSURE AVAILABLE (PSI):	**622,37**	**542,24**	**459,12**	**373,02**	**283,93**	**191,86**	**96,81**	**-1,20**	**-102,18**
JET VELOCITY ACROSS BIT FACE (ft/sec):	222,82	231,74	240,65	249,56	258,48	267,39	276,30	285,22	294,13
HYDRAULIC HORSEPOWER AT BIT (HHP):	157	176	197	220	245	271	299	329	360
HYDRAULIC HORSEPOWER PER SQUARE INCH (HSI):	2,76	3,11	3,48	3,88	4,31	4,77	5,26	5,79	6,35

8.2. Appendix B: E3 OMV

- Hydraulics Calculation: VareL (Imperial)

VAREL
UK LIMITED

RECOMMENDED BIT: DSX616M-A38

COMPANY:	OMV	FIELD:	
WELL NAME:	E3	RIG:	VDD 200.1
FORMATION:	Sandstone, Claystone	AREA:	Gänserndorf

BIT RUN DETAILS		PUMP DETAILS	
HOLE SIZE:	12,25	TYPE SURFACE CONNECTION:	4
DEPTH IN:	1773	MAX OPERATING PRESSURE:	3000
DEPTH OUT:	6744	LINER SIZE:	6

DRILLING FLUID		
TYPE (WATER=1, OIL=2, POLYMER =3):	3	
	DEPTH IN	DEPTH OUT
MUD WEIGHT:	9,2	9,2
PLASTIC VISC:	15,0	16,0
YIELD POINT:	20,0	20,0

LWD / MWD / MOTOR DEATAILS

TYPE:	Motor	PRESSURE DIFFERENTIAL:	970

BHA DETAILS	O.D.	WEIGHT	QUIV. I.D	LENGTH	CASING	I.D.	LENGTH	NOZZLES	
TOP DRILL PIPE:	4,928		4,276	1682	TOP CASING 1:	8,350	1772	LATERAL JET 1:	13
BOTTOM DRILL PIPE:					CASING / OH 2:	12,250	1	LATERAL JET 2:	13
TOP HEAVY WEIGHT:	5,000		3,000	60	CASING / OH 3:			DOWN JET 1:	13
BOTTOM HEAVY WEIGHT:					CASING / OH 4:			DOWN JET 2:	14
TOP DRILL COLLARS:	7,910		2,950	30	CASING / OH 5:			DOWN JET 3:	14
BOTTOM DRILL COLLARS:	8,270		2,830	1	CASING / OH 6:			DOWN JET 4:	14

CA

	O.D.	WEIGHT	QUIV. I.D	LENGTH		I.D.	LENGTH		
TOP DRILL PIPE:	4,8000	0,00	4,0000	6812	TOP CASING 1:	8,3500	3012	LATERAL JET 1:	12
BOTTOM DRILL PIPE:		0,00			CASING / OH 2:	8,5000	3800	LATERAL JET 2:	12
TOP HEAVY WEIGHT:	5,0000	0,00	3,0000	0	CASING / OH 3:	0,0000	0	DOWN JET 1:	12
BOTTOM HEAVY WEIGHT:		0,00			CASING / OH 4:	0,0000	0	DOWN JET 2:	13
TOP DRILL COLLARS:	8,2500		2,8300	0	CASING / OH 5:	0,0000	0	DOWN JET 3:	13
BOTTOM DRILL COLLARS:	0,0000	0,00	0,0000	0	CASING / OH 6:	0,0000	0	DOWN JET 4:	13
								TFA:	0,720

DEPTH IN									
FLOW RATE:	500,00	520,00	540,00	560,00	580,00	600,00	620,00	640,00	660,00
TOTAL PRESSURE DROP FOR SYSTEM (LESS BIT):	1340,66	1376,97	1414,55	1453,41	1493,52	1534,90	1577,54	1621,42	1666,56
AVAILABLE PRESSURE FOR BIT (PSI):	1159,34	1123,03	1085,45	1046,59	1006,48	965,10	922,46	878,58	833,44
PRESSURE DROP ACROSS BIT (PSI):	536,97	580,79	626,32	673,58	722,55	773,24	825,65	879,78	935,62
TOTAL PRESSURE EXPENDITURE FOR SYSTEM (PSI):	1877,63	1957,76	2040,88	2126,98	2216,07	2308,14	2403,19	2501,20	2602,18
STANDPIPE PRESSURE AVAILABLE (PSI):	622,37	542,24	459,12	373,02	283,93	191,86	96,81	-1,20	-102,18
JET VELOCITY ACROSS BIT FACE (ft/sec):	222,82	231,74	240,65	249,56	258,48	267,39	276,30	285,22	294,13
HYDRAULIC HORSEPOWER AT BIT (HHP):	157	176	197	220	245	271	299	329	360
HYDRAULIC HORSEPOWER PER SQUARE INCH (HSI):	2,76	3,11	3,48	3,88	4,31	4,77	5,26	5,79	6,35

The table below is casing drilling activities for the 9 5/8" casing section. It is derivate from the excel sheet well time breakdown of the entire well.

Steps	E3	Depth(m)	T(Hr)
1	P/U;M/U; RIH BHA#3	539	4,3
2	RIH BHA#3 on 5"DP	539	2
3	Drill 13 3/8" Shoe track, 3m new formation	542	3,1
4	Circulate B/U	605	1,1
5	Continue Drilling 12 ¼" (ROP= 20 m/hr)	905	24,3
6	Continue Drilling 12 ¼" (ROP=25 m/h)	1095	15,8
7	Resume Drilling 12 ¼"	1326	7,8
8	Circulate B/U ×4	1460	3,2
9	Continue drilling 12 ¼" (ROP =10-25 m/hr)	1460	13,1
10	Resume Drilling 12 ¼"	1636	27,3
11	Hole cleaning	2054	5,1
12	POOH on elevator	2054	9,6
13	POOH by pump out	2054	6,8
14	RIH on elevator	2054	5,8
15	POOH w/o success	2054	8,8
16	Flow check	2054	0,6
17	Break out and L/D 12 ¼" BHA	2054	3,3
18	RIH SLB wire line tools	2054	1,5
19	SLB logging	2054	4
20	R/D SLB wire line logging	2054	1,5
21	BOP Stack	2054	2,8
22	HPJSM, R/U WTF(Torkdrive)	2054	1,6
23	HPJSM prior run 9 5/8"	2054	0,3
24	P/U; M/U; RIH 9 5/8"	2054	1,3
25	Continue RIH 9 5/8"	2054	7,5
26	Cementing	2054	3
27	WOC	2054	2,5
28	N/D BOP Stack	2054	4,25
29	P/U; M/U; RIH CTT	2054	0,75
30	P/T VBR Ram	2054	0,75
	Total Operating Time		168,1

8.3. Appendix C: Weatherford (WTF)

➢ Hydraulics Calculation

COMPANY:	WTF	FIELD:	
WELL NAME:	WTF	RIG:	
FORMATION:	Sandstone, Claystone	AREA:	

BIT RUN DETAILS		PUMP DETAILS		DRILLING FLUID		
HOLE SIZE:	8,50	TYPE SURFACE CONNECTION:	4	TYPE (WATER=1, OIL=2, POLYMER =3):		2
DEPTH IN:	1746	MAX OPERATING PRESSURE:	11500		DEPTH IN	DEPTH OUT
DEPTH OUT:	6890	LINER SIZE:	6	MUD WEIGHT:	12,0	12,0
				PLASTIC VISC:	15,0	20,0
				YIELD POINT:	20,0	25,0

LWD / MWD / MOTOR DEATAILS

TYPE:	Motor	PRESSURE DIFFERENTIAL:	3000

BHA DETAILS	O.D.	WEIGHT	EQUIV. I.D.	LENGTH	CASING	I.D.	LENGTH	NOZZLES	
TOP DRILL PIPE:	9,625		8,800	1746	TOP CASING 1:	8,350	1745	LATERAL JET 1:	13
BOTTOM DRILL PIPE:					CASING / OH 2:	8,500	1	LATERAL JET 2:	13
TOP HEAVY WEIGHT:					CASING / OH 3:			DOWN JET 1:	13
BOTTOM HEAVY WEIGHT:					CASING / OH 4:			DOWN JET 2:	14
TOP DRILL COLLARS:	7,910		2,950		CASING / OH 5:			DOWN JET 3:	14
BOTOM DRILL COLLARS:					CASING / OH 6:			DOWN JET 4:	14
								T F A :	0,840

	O.D.	WEIGHT	EQUIV. I.D.	LENGTH		I.D.	LENGTH		
TOP DRILL PIPE:	9,6250	0,00	8,8000	6890	TOP CASING 1:	8,3500	1745	LATERAL JET 1:	13
BOTTOM DRILL PIPE:		0,00			CASING / OH 2:	8,5000	5145	LATERAL JET 2:	13
TOP HEAVY WEIGHT:	0,0000	0,00	0,0000	0	CASING / OH 3:	0,0000	0	DOWN JET 1:	13
BOTTOM HEAVY WEIGHT:		0,00			CASING / OH 4:	0,0000	0	DOWN JET 2:	12
TOP DRILL COLLARS:	7,9100		2,9500	0	CASING / OH 5:	0,0000	0	DOWN JET 3:	12
BOTTOM DRILL COLLARS:	0,0000	0,00	0,0000	0	CASING / OH 6:	0,0000	0	DOWN JET 4:	14
								T F A :	0,760

DEPTH IN									
FLOW RATE:	**700,00**	**660,00**	**620,00**	**580,00**	**540,00**	**500,00**	**460,00**	**420,00**	**380,00**
TOTAL PRESSURE DROP FOR SYSTEM (LESS BIT):	1712,96	1856,39	1991,33	2117,76	2235,71	2345,17	2446,14	2538,64	2622,66
AVAILABLE PRESSURE FOR BIT (PSI):	9787,04	9643,61	9508,67	9382,24	9264,29	9154,83	9053,86	8961,36	8877,34
PRESSURE DROP ACROSS BIT (PSI):	767,55	682,34	602,14	526,95	456,77	391,61	331,46	276,32	226,19
TOTAL PRESSURE EXPENDITURE FOR SYSTEM (PSI):	2480,51	2538,73	2593,46	2644,71	2692,48	2736,77	2777,60	2814,95	2848,85
STANDPIPE PRESSURE AVAILABLE (PSI):	**9019,49**	**8961,27**	**8906,54**	**8855,29**	**8807,52**	**8763,23**	**8722,40**	**8685,05**	**8651,15**
JET VELOCITY ACROSS BIT FACE (ft/sec):	267,51	252,23	236,94	221,65	206,37	191,08	175,79	160,51	145,22
HYDRAULIC HORSEPOWER AT BIT (HHP):	313	263	218	178	144	114	89	68	50
HYDRAULIC HORSEPOWER PER SQUARE INCH (HSI):	5,52	4,63	3,84	3,14	2,54	2,01	1,57	1,19	0,88

The Table below is the Weatherford's drilling activities just for the 9 5/8-in section.

Steps	WTF Retrievable rDwC Operation	Time (hour)	Depth (m)
1	PJSM. P/U and M/U 6 – ¾" RSS directional BHA, shallow test Under reamer and RSS RIH same.	2	-
2	R/U casing drive and handling equipment	1	-
3	P/U and M/U shoe joint assembly pre – installed rDwC Latch	1	-
4	RIH with rDwC BHA and 9 5/8" casing to 13 3/8" casing shoe at @550 m	3,58	532
5	Drill out 13 3/8" shoe track and 3 m new hole	1,50	553
6	Continued rDwC with 9 5/8" casing to 2100 m TD @ 30 m/h(ROP)	62	2100
7	Circulate 2 x bottom up	0,57	2100
8	Space out casing M/U 9 5/8" casing hanger. Land Casing	1	2100
9	P/U and M/U WRRD. RIH to top of Latch Assembly @ 2073 m	4,25	2100
10	Stab WRRD in Latch, pull to unlock Latch. Continue POOH WRRD with Latch and rDwC BHA.	3,75	2100
11	Break out and L/D BHA	1,50	2100
12	PJSM Drop Latchable Cement Plug. M/U cement head and cement lines. Test same	2	2100
Total (Hours)		**84,2**	
Total (Days)		**3,51**	

X1 to X10 are the events (sub-operations coming from OMV (E3), Schlumberger (M1) and Weatherford). These events are capital to evaluate the economic feasibility study.

HPJSM; P/U; M/U; RSS DD BHA [hr] X1	
Distribution	Triangular
Minimum	2
Most likely	3,25
Maximum	4,3

R/U casing drive and handling equipment [hr] X2	
Distribution	Triangular
Minimum	1
Most likely	1,2
Maximum	1,5

RIH with rDwC BHA 9 5/8" casing to casing shoe [hr] X3	
Distribution	Triangular
Minimum	2
Most likely	2,79
Maximum	3,58

Drill 13 3/8" shoe track and 3 m new formation hole [hr] X4	
Distribution	Triangular
Minimum	1,5
Most likely	2,3
Maximum	3,1

Continue rDwC drilling 9 5/8" casing to @TD [hr] X5	
Distribution	Triangular
Minimum	40,1
Most likely	51
Maximum	62

Circulate B/U [hr] X6	
Distribution	Triangular
Minimum	1
Most likely	2,1
Maximum	3,2

POOH with rDwC BHA [hr] X7	
Distribution	Triangular
Minimum	3,75
Most likely	6,67
Maximum	9,6

Break out and L/D BHA 12 1/4" [hr] X8	
Distribution	Triangular
Minimum	1,5
Most likely	2,4
Maximum	3,3

Cement 9 5/8" casing [hr] X9	
Distribution	Triangular
Minimum	6
Most likely	8
Maximum	10

Lay Down BHA Pre-Instalation rDwC assembly [hr] X10	
Distribution	Triangular
Minimum	3
Most likely	3,62
Maximum	4,25