Chair of Drilling and Completion Engineering

Master's Thesis

Managed pressure casing drilling analysis for an appraisal well in Jordan

Amro Al Hmoud

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This work is dedicated to my family, friends and to the one who always supported me no matter what, even though we were not able to physically meet, but she was the source of my inspiration.

Abstract

Drilling technologies has been developing and evolving ever since the discovery of oil to the human kind. Many reasons encouraged this development, the vast investment and the time to come up and the slightest maturing of this field of science. One of the major yet simplest ways to have one step forward is the ability to use two or multiple technologies in purpose of mitigating each other's flows and cons.

Conventional drilling methods have been a blast to the world of drilling, yet, they have their share of flaws such as tripping in and out operations, pipe handling, and some of these flaws might lead to an actual risk of well control problems. Thus, it was a motive to innovate solutions to attenuate those limitations.

Casing drilling technology became a solution for many of the conventional drilling methods imperfections such as narrowing down the tripping operations to the point of no tripping out post reaching the planned depth, which helped reducing time which usual many hours are spent on using conventional methods.

As for managed pressure drilling technology, it has proven it benefits on many projects by achieving a safer, more efficient and cost effectiveness. Also, it gives the ability to closely monitor the well and better accuracy determining or detecting aberrations encountered, thus an enhanced response capability.

In this case study, several mud losses in different depths varying between partial and complete mud loss, and also a premature casing seat and pipe stuck problem occurred. All combined lead to a major non-productive time which increased the overall time spent and the cost dramatically.

This thesis will focus on implementing both managed pressure and casing drilling technologies since both technologies proved worldwide their applicability for overcoming the problems encountered in this case study, which conventional drilling method was used in. The well hydraulic analysis and economical assessment of new technologies are provided and eventually conclude the outcome of applying the managed pressure casing drilling together.

Zusammenfassung

Die Bohrtechnologien haben sich seit der Entdeckung des Erdöls für die Menschheit entwickelt und weiterentwickelt. Viele Gründe haben diese Entwicklung begünstigt, die enormen Investitionen und die Zeit, die nötig war, um diesen Bereich der Wissenschaft zu entwickeln und reifen zu lassen. Eine der wichtigsten und zugleich einfachsten Möglichkeiten, einen Schritt nach vorne zu machen, ist die Möglichkeit, zwei oder mehrere Technologien zu nutzen, um die Vor- und Nachteile der jeweils anderen abzumildern.

Konventionelle Bohrmethoden haben die Welt des Bohrens beflügelt, aber sie haben auch ihre Schwächen, wie z.B. das Ein- und Auslösen von Operationen, die Handhabung von Rohren, und einige dieser Schwächen können zu einem tatsächlichen Risiko von Problemen bei der Bohrlochkontrolle führen. Daher war es ein Motiv, innovative Lösungen zu finden, um diese Einschränkungen abzuschwächen.

Die Casing-Drilling-Technologie wurde zu einer Lösung für viele der Unzulänglichkeiten der konventionellen Bohrmethoden, wie z.B. die Einschränkung der Auslösevorgänge bis zu dem Punkt, an dem nach Erreichen der geplanten Tiefe kein Auslösen mehr erfolgt, was dazu beitrug, die Zeit zu reduzieren, für die bei konventionellen Methoden normalerweise viele Stunden aufgewendet werden.

Die Technologie des gesteuerten Druckbohrens hat sich bei vielen Projekten bewährt, da sie sicherer, effizienter und kosteneffektiver ist. Außerdem bietet sie die Möglichkeit, das Bohrloch genau zu überwachen und Abweichungen mit höherer Genauigkeit zu bestimmen oder zu erkennen, was eine verbesserte Reaktionsfähigkeit ermöglicht.

In dieser Fallstudie traten mehrere Spülungsverluste in verschiedenen Tiefen auf, die zwischen teilweisem und vollständigem Spülungsverlust variierten, sowie ein Problem mit einem vorzeitigen Gehäusesitz und einem festsitzenden Rohr. Alles zusammen führte zu einer großen unproduktiven Zeit, die den gesamten Zeitaufwand und die Kosten dramatisch erhöhte.

In dieser Arbeit wird der Schwerpunkt auf die Implementierung sowohl der Managed-Pressure- als auch der Casing-Drilling-Technologie gelegt, da beide Technologien weltweit ihre Anwendbarkeit zur Überwindung der in dieser Fallstudie aufgetretenen Probleme bewiesen haben, bei der konventionelle Bohrverfahren eingesetzt wurden. Die brunnenhydraulische Analyse und die wirtschaftliche Bewertung der neuen Technologien werden zur Verfügung gestellt, um schließlich das Ergebnis der Anwendung des Managed Pressure Casing Drilling zusammenzufassen.

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Acronyms

TVD	Total Vertical Depth
TMD	Total Measured Depth
GL	Ground Level
LOT	Leak-off Test
FIT	Formation Integrity Test
NPT	Non-Productive Time
BHA	Bottom Hole Assembly
LCM	Lost Circulation Material
SG	Specific Gravity
POOH	Pull Out of Hole
RPM	Revolutions Per Minute
RIN	Run In Hole
TOC	Top Of Cement
BOB	Blow Out Preventor
DP	Drill Pipe
DC	Drill Collar
SBP	Surface Back Pressure
CD	Casing Drilling
MPD	Managed Pressure Drilling
MPCD	Managed Pressure Casing Drilling
ECD	Equivalent Circulation Density
OBD	Over Balanced Drilling
UBD	Under Balanced Drilling
RCD	Rotating Control Device
CCS	Continues Circulation System
DGD	Dual Gradient Drilling
PMPD	Pressurized Managed Pressure Drilling
ROP	Rate Of Penetration
YP	Yield Point
LAM	Light Annular Mud
PV	Plastic Viscosity

OBM	Oil Base Mud
WBM	Water Base Mud
NRV	Non-Return Valve
PWD	Pressure While Drilling
CDS	Casing Drilling System
DLA	Drill Lock Assembly
LWD	Logging While Drilling
MWD	Measure While Drilling
RSS	Rotary Steerable System
PDDP	Pump Down Displacement Plug

Chapter 1 Introduction

1.1 Field Overview

The Risha Concession covers approximately 7,400 km2 in North-eastern Jordan with an approximate of 2-3 trillion cubic feet of natural gas, bordering Syria, Iraq and Saudi Arabia. Elevation is around 850 m above mean sea leave (amsl). Topography is a flat desert plain covered by thin cherty gravels above limestone rubble, dissected by shallow sand-filled wadis.

The planned well objectives are to delineate and explore the gas bearing reservoir of Risha Formation, the well was anticipated to be horizontally (max inclination 89 degrees) penetrate Risha Formation at True Vertical Depth (TVD) of 2655 m (GL) with horizontal displacement of 550m.The well penetrated Risha formation horizontally, well inclination at final depth 3036.5m TMD (2652.14m TVD) was 86.5 degrees (projected) with horizontal displacement of 487.08m and 42.8 degrees azimuth. Last deviation reading was 86.3 degrees at depth 3020m TMD (2651.27m TVD).

The well was spudded-in on 21st, May-2004, TMD 3036.5m was reached on 9th March, 2006, slotted 4 ½" liner was run to depth m 3035m TMD and hanged inside the 7" casing at depth 2555m TMD. On 19th, March, 2006 the well was completed with 3 ½" tubing and 7" Baker- type R-3 packer at depth 2447m, end of tubing was at depth 2518.8m. After well testing using down hole pressure gauges the well was acidized on 16th, April, 2006. After well cleaning the rig was released on 24th, April, 2006.

Two drilling rigs (Rum & Jerash) were utilized to drill this well, Rum rig from the surface to depth 1320m including running and cementing the 9 5/8" casing, this lasted from spud-in date to 29th January, 2005. Jerash rig was utilized to drill the well from this point to the final depth including well's completion, this lasted from 13th December, 2005 to 24th, April, 2006.

1.2 Foreseen Challenges

A shallow geohazard assessment of the geological section down to 1400m has been completed, using the data from offset wells and some of the seismic data. The consistency of the shallow geology across the area, based on the seismic data, suggest that it is likely to be representative. Risks investigated in the Shallow Hazard Assessment are summarised as follows (Appendix A):

- Overpressured water flow: The potential for experiencing an over-pressured water flow within the shallow section from ground level to the limit of this assessment at 1450±44m BGL would be considered to be Negligible based on nearby offset wells. Underbalanced drilling will increase the potential for overpressured water influx, as experienced in one of the offset wells at ~250m in the Kurnub and possibly also the underlying Ma'in.
- Unconsolidated, weak or mobile layers susceptible to collapse into wellbore: Data from the offset wells, indicate the risk of experiencing tight hole, caving and stuck pipe within the shallow section, particularly in the Ma'in and Khish-Sha Formations is HIGH.
- Drilling Fluid Loss potential: Based on offset well experience there is considered to be between surface and the top of the Mudawwara Formation at 1272±38m.
- Gas migration routes in event of underground blow-out: In the event of an underground blow-out, the risk of gas reaching the surface in the vicinity of the well is considered to be HIGH. Any gas released might be expected to follow the path of least resistance to rise towards the surface; this path is considered to be the drilled wellbore or the adjacent fractured and porous formation.
- Formation integrity: no leak-off or formation integrity data was acquired in the NPC wells

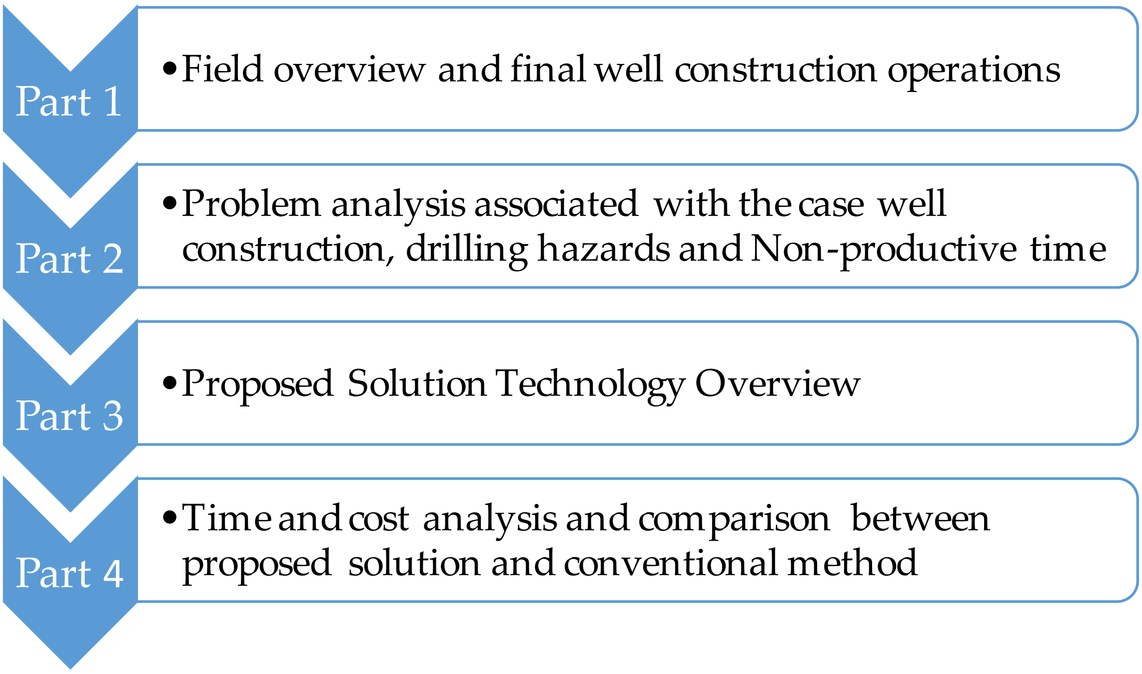
1.3 Objectives and Scope of Work

The main goal of this work is to analyse the case project operations and problems during the well construction, to conclude the root problems that caused the high NPT during the well construction, hence, propose a solution that helps overcoming those problems and thus, reduce overall cost and time required for the well construction.

Scope of work in this thesis:

- Analyse well operation and data, drilling hazards from offset wells and problems faced during project well construction.
- Propose solution, technology back ground, value added by applying it and its limitation.
- Time and Cost analysis of the proposed solution and comparing it with the conventional method.

1.4 Thesis Structure



Chapter 2 Problem Analysis and Solution Proposing

2.1 Problem Analysis

2.1.1 Actual well and Problems Encountered

2.1.1.1 Well Program

The well was designed as following:

- 26" Hole/ 20" casing to depth 35m (optional)
- 17 1/2" Hole/ 13 3/8" casing to depth 501m TVD
- 12 1/4" Hole/ 9 5/8" casing to depth 1331 m TVD
- 8 1/2" hole/ 7" casing to depth 2602 m TVD 2658m TMD
- 6" open hole to final depth at 2 664.5 m TVD 3133m TMD
- KOP @ 2400m

2.1.1.2 Actual Well

During drilling, the program was changed due to the severe mud losses encountered, and as a treatment, a total of 17 cement plugs were spot to depth 381.5m without any success of sealing the loss zones.

As a result of that, the well was drilled as following:

- 26" Hole was cancelled as the first loss zone was encountered at depth 111m.
- 17 1/2" Hole was drilled to depth 381.5m and the 13 3/8" casing was set at depth 370m, couldn't run the casing deeper.
- 12 1/4 " Hole was drilled to depth 1320 m, and 9 5/8" casing was set at depth 1319m, the casing was cemented in two stages with DV at depth 318m.
- 8 1/2" Hole was drilled to depth 2686 m TMD 2670m TVD, 7" liner was hanged inside 9 5/8" casing at depth 1150m with shoe at depth 2682m TMD 2606m TMD.
- 6" Hole was drilled to depth at 3036.5m TMD (2655m TVD).

- Slotted 4 ½" liner was run to depth 3035.5m TMD, and hanged inside the 7" casing at depth 2555m TMD.

The field lithology is showing in Appendix B. The well penetrated the following formations at the following depths:

Table 1. Formation Tops

EPOCH	AGE	FORMATION	TVD Depth RTKB (M)
Tertiary	Eocene	Sara	Surface
	Paleocene	Taqiyeh	107
Cretaceous	Maastrichtian	Ghareb	131
	Turonian	WadiEssir	175
	Albian	Kurnub	239
Triassic	Scythian	Ma'in	285
Silurian	Ludlovian	Khish-sha	436
	Wenlockian	Mudawwara	1315
Ordovician	L.Ashgillian	Risha	2603

Drilling Bits

Total of 35 Bits were used to drill this well as following:

a- <u>17 1/2″ Bits:</u>

Total of 6 drilling bits were used to drill the 17 1/2" hole as following:

- One is steel tooth.
- Five are Tungsten carbide bits.

b- <u>12 ¼″ Bits:</u>

Total of 12 drilling bits) were used to drill 12 ¼″ as following:

- Seven are steel tooth (one for drilling out floating equipment and cement inside casing).
- Five are Tungsten carbide bits.

c- <u>8 ½″ Bits:</u>

Total of 7 drilling bits were used to drill the 8 ½″ hole as following:

- Two are steel tooth (one bit was used to drill the floating equipment and cement inside the casing)
- Five bits are tungsten carbide

d- <u>6″ Bits:</u>

Total of 9 bits were used to drill the 6″ hole as following:

- Six tungsten carbide bits

- Three Smith PDC bits type MO9PX achieved good performance drilling this section, this proved that this type of bits are the most suitable to drill this hole phase in the horizontal wells with conditions that the well is junk free.

e- 5 7/8" Bits:

- One steel tooth 335 CODE was used to drill the 7" floating equipment and cement inside the casing.

f- 3 3/4" Bits:

- One steel tooth bit was used to make a trip inside the 4 1/2" liner.

Drilling Fluid

- The 17 1/2" & 12/4" hole were drilled using water-bentonite based mud with 1.03 SG
- 8 1/2" Hole was drilled using KCl-Polymer mud with CaCO3 as a weighting agent, 1.24-1.35 SG, 5 ml max filtration and 10-11 PH
- 6" Hole was drilled using KCl-Polymer mud 1.03 SG, 5 ml max filtration and 10-11 PH and 12-15.

It's obvious that huge amounts of chemical were consumed to drill the 17 ½" & 12 ¼" because of the severe losses occurred during the drilling of these holes. Total chemical consumption for the well and per well phase are shown in the following table:

Table 2. Chemical Consumption

No.	Chemical	Unit kg/ sx	17 1/2" hole		12 1/4" hole		8 1/2" hole		6" hole		Total	
			SX	M T	SX	MT	SX	MT	SX	MT	SX	M T
1	Attapulgite	25	0.0	0.0	440.0	11.0	0.0	0.0	0.0	0.0	440.0	11.0
2	Benex	1	236.0	0.2	29.0	0.0	0.0	0.0	0.0	0.0	265.0	0.3
3	Bentonite Addaco	25	6072.0	151.8	2735.0	68.4	0.0	0.0	0.0	0.0	8807.0	220.2
4	Bentonite SEPICO	25	0.0	0.0	14135.0	353.4	0.0	0.0	0.0	0.0	14135.0	353.4
5	Bentonite X	30	0.0	0.0	1334.0	40.0	0.0	0.0	0.0	0.0	1334.0	40.0
6	Bentonite y	22.7	0.0	0.0	3485.0	79.1	0.0	0.0	0.0	0.0	3485.0	79.1
7	Cacl2	36.3	23.0	0.8	55.0	2.0	0.0	0.0	0.0	0.0	78.0	2.8
8	Caco3	50	0.0	0.0	20.0	1.0	0.0	0.0	0.0	0.0	20.0	1.0
9	CaCO3	1000	0.0	0.0	0.0	0.0	96.0	96.0	0.0	0.0	96.0	96.0
10	CAUSTIC SODA	25	0.0	0.0	0.0	0.0	44.0	1.1	34.0	0.9	78.0	2.0
11	CMC HV	25	258.0	6.5	762.0	19.1	0.0	0.0	0.0	0.0	1020.0	25.5
12	CMC LV	25	325.0	8.1	862.0	21.6	0.0	0.0	0.0	0.0	1187.0	29.7

13	Coustic Soda	50	50.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	50.0	2.5
14	Coustic Soda	25	29.0	0.7	332.0	8.3	0.0	0.0	0.0	0.0	361.0	9.0
15	FCL	25	125.0	3.1	25.0	0.6	27.0	0.7	0.0	0.0	177.0	4.4
16	Gypsum	25	0.0	0.0	20.0	0.5	0.0	0.0	0.0	0.0	20.0	0.5
17	Hay	25	50.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	50.0	1.3
18	HEC	25	0.0	0.0	19.0	0.5	0.0	0.0	0.0	0.0	19.0	0.5
19	KCl	1000	0.0	0.0	12.0	12.0	65.0	65.0	40.0	40.0	117.0	117.0
20	LOW FOAM	DR	0.0	0.0	0.0	0.0	0.0	0.0	2.0	DR	2.0	2.0
21	Mica -C	25	16.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	16.0	0.4
22	Mica -F	25	0.0	0.0	566.0	14.2	0.0	0.0	0.0	0.0	566.0	14.2
23	Mill Seal (C)	25	0.0	0.0	36.0	0.9	0.0	0.0	0.0	0.0	36.0	0.9
24	Mill Seal (M)	25	0.0	0.0	471.0	11.8	0.0	0.0	0.0	0.0	471.0	11.8
25	Olive Core (Jift)	57	168.0	9.6	145.0	8.3	0.0	0.0	0.0	0.0	313.0	17.8
26	PAC-HV	25	0.0	0.0	0.0	0.0	47.0	1.2	105.0	2.6	152.0	3.8

Bottom Hole Assembly (BHA)

Table 3. Bottom Hole Assembly

DATE		HOLE SIZE	DEPTH m		BHA
FROM	TO		FROM	TO	
21-5-2004	23-5-2004	17 1/2"	Surface	76	Bit 17 1/2, Bit S., 1 JD C 8", X.O.S.
23-5-2004	25-5-2004	17 1/2"	76	111	Bit - sub - 1x9 1/2" DC - 17 1/2" S. stab - 1x9 1/2" DC - 91/2" DC - XO.
25-5-2004	27-5-2004	17 1/2"	111	111	B.H.A: Bit, B. S., 3Jx9 1/2" D.C, X.O.S, X.O.S.
27-5-2004	28-5-2004	17 1/2"	111	111	B.H.A: bit, bit S., 3Jx9 1/2 DC, X.O.S, 2Jx8" D.C, X.O.S.
28-5-2004	30-5-2004	17 1/2"	111	129	B.H.A: bit, bit S., 1JDC9 1/2", STB 17 1/2", 1J D.C 9 1/2", STB 17 1/2", 1J D.C 9 1/2", X.O.S, 3J DC. 8" , X.O.S.
30-5-2004	30-5-2004	17 1/2"	129	129	B.H.A: 11.5" Junk basket, 1 stand x 8" D.C, X.O.S.
30-5-2004	6-6-20043	17 1/2"	129	354	B.H.A: Bit, Bit S. 3x9 1/2 D.C, X.O.S, 11x8" D.C, X.O.S,3x4 ½ H.W.D.P
6-6-20043	5-7-2004	17 1/2"	354	381.5	BHA: Bit, bit sub,15x8" D.C, 8" D.J, 3x8" D.C, X.O.C 9x41/2 H.W.D.P.
5-7-2004	6-7-2004	17 1/2"	381.5	381.5	BHA: 17 1/2" bit, bit sub, 12x8" DC, XO, 2x4 1/2" DP.
6-7-2004	19-7-2004	17 1/2"	381.5	381.5	BHA: 17 1/2" bit, bit sub, 15x8" Dc, 8" Drlg Jar, 3x8" DC, XO, 9x4 1/2" HWDP, 4 1/2" DP.
19-7-2004	28-10-2004	12 1/4"	381.5	1057	BHA: Bit, B. S., 13 x 8" DCS, 8" D. Jar, 2 x 8" DC, X.O. Sub, 9 x 4 1/2" H.W.D.P and DP to surface.
28-10-2004	18-11-2004	12 1/4"	1057	1057	12 1/4" Bit, B.S with float valve, 13 x 8" DC, Dlg Jar, 2x8" DC, 9x4 1/2" HWDP.

18-11-2004	22-11-2004	12 1/4"	1057	1057	12 1/4" bit + 3x8" D.C + 8" D. jar + 1x8" D.C + X-sub +7x 4 1/2" HWDP
22-11-2004	2-12-2004	12 1/4"	1057	1057	12 1/4" Bit, 5x8" DC, 8 Drlg jar, 1x8" DC, XO, 7"x4 1/2" HWDP.
2-12-2004	5-12-2004	12 1/4"	1057	1057	BHA: Bit, Bit Sub, 12x8" DC, D. jar, 1x8" D.C, X.O.Sub7x4 1/2" HWDP & 4 1/2" DP to surface.
5-12-2004	7-12-2004	12 1/4"	1057	1057	Bit, Bit Sub, 8x8" D.C, drlg jar, 1x8" DC, X-over, 7x4 1/2" HWDP.
7-12-2004	23-1-2005	12 1/4"	1057	1230	12 1/4" Bit, Bit Sub, 12x8" DC, 8" drlg jar, 1x8" DC XO, 7x4 1/2" HWDP.
14-12-2005	18-12-2005	8 1/2"	1230	1355	Bit J.S, BS, 13x6 1/2" DC, X.O.S, DJ, X.O.S, 2x6 1/2 DC, X.O.S, 9x5" HWDP.
18-12-2005	27-12-2005	8 1/2"	1355	1870	Bit, NBS, short DC 6 1/2, STB, DC, STB, 12x6 1/2 DC X.O.S, D Jar X.O.S, 2x6 1/2" DC, X.O.S + 9x5 HWDP.
27-12-2005	5-1-2006	8 1/2"	1870	2400	BHA: 8 1/2" Bit, 8 1/2" NBS, short DC, 8 1/2 STB, 6 1/2" DC, 8 1/2" STB, 12x6 1/2 DC X.O.S, D Jar X.O.S, 2x61/2" DC, X.O.S + 9x5 HWDP.

Time Distribution

The well was spudded-in on 21st, May-2004, TMD 3036.5m was reached on 9th March, 2006, slotted 4 ½" liner was run to depth m 3035m TMD and hanged inside the 7" casing at depth 2555m TMD. On 19th, March, 2006 the well was completed with 3 ½" tubing and 7" Baker- type R-3 packer at depth 2447m, end of tubing was at depth 2518.8m. After well testing using down hole pressure gauges the well was acidized on 16th, April, 2006. After well cleaning the rig was released on 24th, April, 2006.

The two Rigs spent 389 days on the location including 38 days waiting on material and service companies and 18 days for drilling rigs maintenance.

Table 4. Time Break Down

<table>
<tr><th colspan="2">PHASE</th><th>FROM</th><th>TO</th><th>hrs</th><th colspan="3">DAYS</th></tr>
<tr><td rowspan="2">17 ½"</td><td>DRILLING TO 392m</td><td>21-MAY,2004</td><td>19-JULY,2004</td><td>1427.00</td><td>59.46</td><td rowspan="2">64.08</td><td rowspan="5">255.67</td></tr>
<tr><td>CASING RUN & CEMENT 13 3/8"</td><td>19-JULY,2004</td><td>24-JULY, 2004</td><td>111.00</td><td>4.63</td></tr>
<tr><td rowspan="3">12 ¼" HOLE</td><td>DRILLING F 392m TO 1043m</td><td>24-JULY, 2004</td><td>27-OCT, 2004</td><td>2311.75</td><td>96.32</td><td rowspan="3">191.59</td></tr>
<tr><td>WORK ON STUCK PIPE</td><td>27-OCT, 2004</td><td>16-NOV, 2004</td><td>516.50</td><td>21.52</td></tr>
<tr><td>BACK -OFF</td><td>16-NOV, 2004</td><td>18-NOV, 2004</td><td>60.00</td><td>2.50</td></tr>
</table>

	REAMING	18-NOV, 2004	15-DEC, 2004	648.00	27.00		
	BLIND DRILLING F 1043m TO 1320m	15-DEC, 2004	25-JAN, 2005	971.00	40.46		
	RUN & CEMENT 9 5/8"CASING	25-JAN, 2005	29-JAN, 2005	91.00	3.79		
			SUB TOTAL	6136.25	255.67	255.67	255.67
FROM 30-JAN, 2005 TO 12-DEC, 2005 MOVE RUM RIG, WAITING ON JERASH RIG, MOVE & RIG UP JERASH RIGON LOCATION							
8 ½" HOLE	DRILLING F 1320m TO 2465m	13-DEC, 2005	8-JAN, 2006	624.00	26.00	47.00	54.35
	PLUG BACK, REDRILL F 2400-2465m	8-JAN, 2006	17-JAN, 2006	235.00	9.79		
	DRILLING F 2465-2607m	17-JAN, 2006	25-JAN, 2006	189.50	7.90		
	RUN & CEMENT 7" LINER	25-JAN, 2006	29-JAN, 2006	79.50	3.31		
	CEMENT SQUEEZE TOL	29-JAN, 2006	4-FEB, 2006	143.00	5.96	7.35	
	7" SCRAPER TRIP	4-FEB, 2006	5-FEB, 2006	33.50	1.40		
6" HOLE	DRILLING F 1320m TO 2465m	5-FEB, 2006	8-JAN, 2006	275.50	11.48	31.44	41.81
	WELL INTEGRITY TEST	8-JAN, 2006	20-FEB, 2006	83.50	3.48		
	REAMING AFTER TEST	20-FEB, 2006	24-FEB, 2006	106.00	4.42		
	DRILLING From 2753m TO 3036.5m TD	24-FEB, 2006	9-MAR, 2006	289.50	12.06		
	WAITING ON 4 1/2" LINER HANGER	9-MAR, 2006	16-MAR, 2006	187.50	7.81	10.38	
	RIH 4 1/2" SLOTTED LINER	16-MAR, 2006	19-MAR, 2006	61.50	2.56		
COMPLETION& TESTING	WELL COMPLETION	19-MAR, 2006	21MAR, 2006	70.00	2.92	37.59	37.59
	WELL FLOWING	21MAR, 2006	28-MAR, 2006	215.00	8.96		
	DOWN HOLE PRESSUREMEASUREME NT	28 MAR, 2006	16 APR, 2006	415.00	17.29		
	ACIDIZING	16 APR, 2006	20 APR, 2006	87.00	3.63		
	WELL CLEAN- UP	20 APR, 2006	24 APR, 2006	115.00	4.79		
			SUB TOTAL	3210.00	133.75	133.75	133.75
			GRAND TOTAL	9346.25	389.43	389.43	389.43

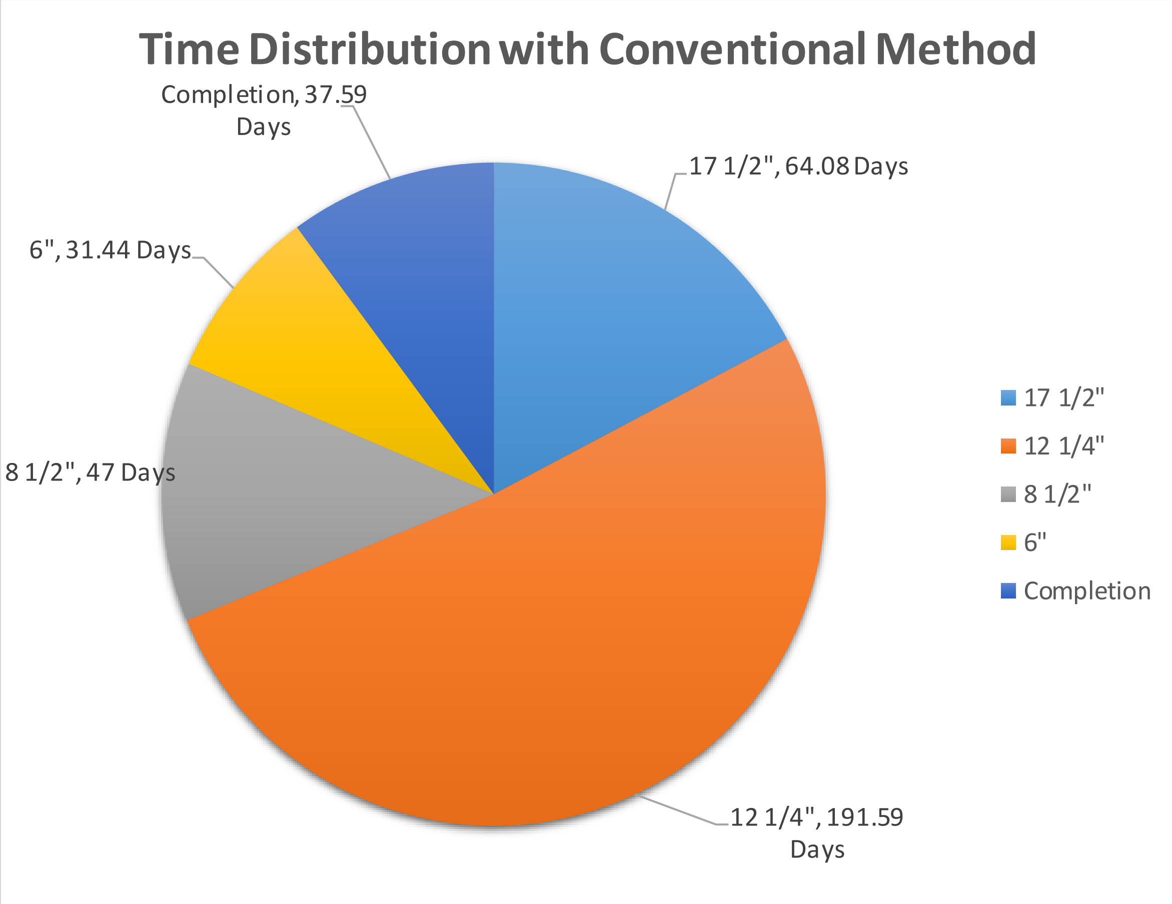


Figure 1 Time Break Down

Based on the chart created from the table, it can be concluded that the 17 ½" And 12 ¼" sections, even though that it is the surface part and intermediate part with a total depth of 1320m, they are the major time consumers with a 69% of the total time spent over well construction operations. This major time was caused by various problems encountered during the well construction.

All operations performed during each phase of the well have been categorised into productive time, Non-Productive time and lost time, as shown in table 5.

Table 5. Time Distribution

			17 1/2" HOLE	12 1/4" HOLE	8 1/2" HOLE	6" HOLE	COMPLETION & TESTING	TOTAL hrs	TOTAL days
PRODUCTIVE TIME	DRILLING	DRILLING	186.25	357.5	471.5	248.5		1263.75	52.66
		TRIP	86.75	399.5	199.5	214.5		900.25	37.51
		AERATED MUD DRILLING		148.5				148.50	6.19
		CIRCULATION	90.5	126	54.5	47		318.00	13.25
		MIXING MUD			43			43.00	1.79
		REAMING	134.5	89	3.5	15.5		242.50	10.10
		JUNK OPERATION			36	125.5		161.50	6.73
	CASING	WOC	15	24.5	11.5			51.00	2.13
		RUNNING	24	31	42.5	61.5		159.00	6.63

		CLEANING	12		56			68.00	2.83
		DOC			5.			5.50	0.23
		CEMENTING	16	7.5	4			27.50	1.15
		SCRAPER			17.5			17.50	0.73
		CEMENT SQUEEZE			183			183.00	7.63
		WOC			54			54.00	2.25
	TESTING&COMPLETION	CLOSE				28	472.5	500.50	20.85
		FLOW				26.5	317	343.50	14.31
		TRIP				27.5	45	72.50	3.02
		WORK ON WELL HEAD & BOP	40	13	59	1	13.5	126.50	5.27
		ACDIZING.					33	33.00	1.38
		SWABING					5	5.00	0.21
		PRODUCTION LINE					11	11.00	0.46
		WIRELINE					7	7.00	0.29
NON-PRODUCTIVETIME	LOSSES	WOC	170	515.5				685.50	28.56
		TRIP	137	694				831.00	34.63
		DOC	162.5	498				660.50	27.52
		CEMENTING	38	76.75				114.75	4.78
		TREATMENT	39	191				230.00	9.58
	STUCK	WORK ON STUCK PIPES	150.5	506				656.50	27.35
		EL BACK OFF		60				60.00	2.50
		REAMING AFTER STUCK						0.00	0.00
		FISHING	13.5	18				31.50	1.31
LOST TIME	REPAIR & MAINTNANCE		222.5	136	60.5	8.5		427.50	17.81
	ON- WAITING	MATERIAL (WATER)		592.5				592.50	24.69
		OTHER MATERIALS (BENTONITE & CEMENT)		114				114.00	4.75
		MATERIAL (LINER HANGER)				187.5		187.50	7.81
		(DIRECTIONAL DRILLING CO.)				12.5		12.50	0.52
		WEATHER			2			2.00	0.08
		TOTAL hrs	1538	4598	1304	1004	904	9348	
		TOTAL days	64.1	191.6	54.3	41.8	37.7	389.5	389.5

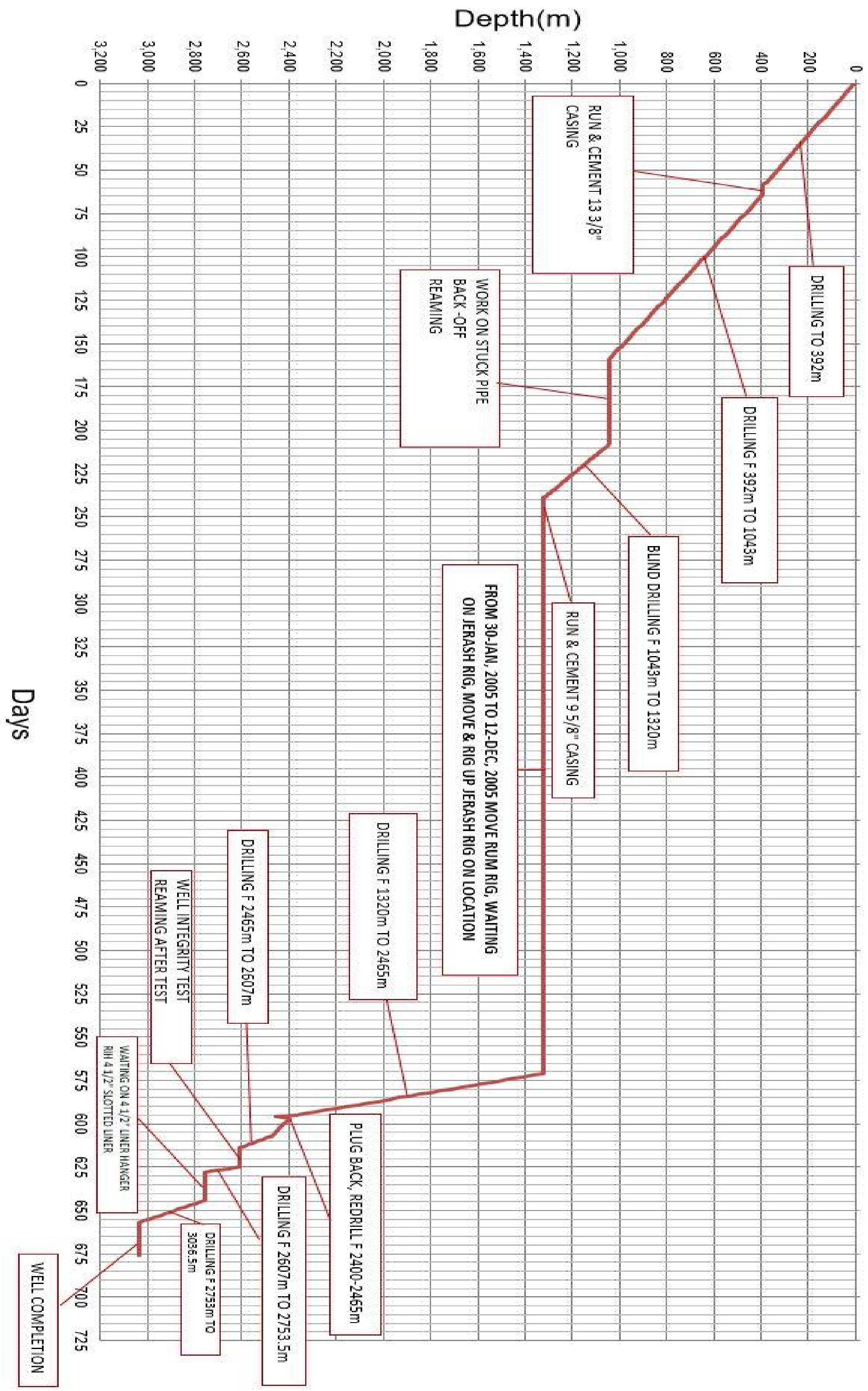


Figure 2. Actual Well Time-Depth Diagram

2.1.1.3 Problems Encountered

A partial and sever mud loss occurred at different depths in the 17 ½" and 12 ¼" holes. Mud loss solutions have been attempted such as LCM, gunk plugs and cement plugs but without any success to seal the loss zones. Because of this the 13 3/8" casing was run premature at depth of 370m instead of 500m as programmed. Additionally, an attempt of using aerated mud drilling technology was applied to drill the interval 1036-1043m, but also without success.

A water-bentonite based mud was used to drill the 17 ½" & 12 ¼" hole with a 1.03 SG, which is a typical drilling mud for the upper part, yet is not the optimal option to be used in a sandstone layers, which made it possible to have mud losses issues and probably a swelling which led to a drill pipe stuck problem.

Drill pipe stuck issue was faced as well due to sand caving from Main & Kurnub formations. After freeing the stuck pipe there was an attempt to seal the losses zones by cement plugs, but without success. Eventually blind drilling was performed to drill from 1043 to a final depth of 1320.Based on the history of the previous projects, the losses are mostly caused by the highly fractured area, which can't be dealt with using normal loss circulation materials (LCM), which required finding other solutions to overcome those problematic sections of formation.

1- 17 ½" Hole / 13 3/8" Casing (21/05/2004 to 24/07/2004)

- This well was spudded-in on 21st May- 2004, at 9:00 pm
- The hole was drilled to depth 381.5m, the 13 3/8" casing was set at depth 370m, couldn't run the casing deeper.
- Hole depth of 381.5m was reached on 30th June-2006.
- From 30th June to 19th July try to continue drilling below this point without progress.
- 64 days were spent to drill this hole.
- The 17 1/2" hole was drilled using water-based mud.
- Total loss of circulation occurred at the intervals 66, 104, 370 -380m.
- Total of 17 cement plugs (797 bbl. of cement slurry) were pumped to seal the losses zones, 8 of them were spot to seal the lower zone (374-381m) without success.
- Because of the severe losses the 13 3/8" casing was run premature at depth 370m instead of 500m as programmed.

While drilling this hole the drill string got stuck two times as following:

- ❖ In the period from 22nd to 27th June-2004 at drilling depth 378.5m and while POOH after DOC (TOC @ 375m), drill string got stuck at depth 270m, work on pipe, pump acid three times and RIH 2 3/8" string in the 17 1/2" annulus to free the pipes

- On 7th July-2004 at drilling depth 381.5m and while POOH after DOC@(TOC @ 358m), bit nozzles were plugged, POOH, drill string got stuck at depth 340m, work on pipe and got the pipes free, continue POOH, drill string got stuck at depth 300m, work on pipe and got the pipes free, after POOH the string to surface found 2 nozzles plugged and the bit balled with clay.

2- 12 <u>1/4" Hole / 9 5/8" Casing (24/07/2004 to 29/01/2005)</u>

While drilling this hole the drill string got stuck two times as following:

- On 17th August-2004 at 722 m drilling depth, pipe got stuck while POOH @ 710 - 720m, work on the pipe with 15-30 T over pull and free it (lost 35m3 mud during handling the stuck).

- On 18th August-2004 at 724 m drilling depth, pipe got stuck while drilling (adding joint), work on the pipe and back reaming to 714m to free it (bad mud properties, shortage in mud chemicals).

- On 4th October-2004 at 1010 m drilling depth, pipe got stuck while washing out the gunk plug at depth 961m (adding joint), circulation and work on pipe for 3 hours then free the stuck pipe.

- On 27th October start drilling using the aerated mud as a drilling fluid at drilling depth 1043 m (no return, W/ air + mud) the string was stuck. Work on pipe and try to free the stuck pipe without success. After 24 days trying to free the stuck pipes without progress, on 15th November back off the string electrically at 858m with the drilling bit at 1009m. Bit, B. sub, 13 joint 8" DC + drilling jar + 2 joint 8" D.C + X-over + 1joint HWDP were lost in the hole. 27 days were spent to ream the hole and to drill a new hole (side track) parallel to the fish

- In the period from 25th to 29th Jan-2005 run and cement the 9 5/8" casing as following:
  - Casing shoe at 1320m DV @ 400m.
  - Casing weight is 47 lb/ft, N-80 grade and BTC connection.
  - The casing was cemented in two stages as following:
    - First stage: 90 bbls of 1.9 SG & 200 bbls of 1.5 SG cement slurry, the cement was displaced by 306 bbls of mud
    - Second stage: 85 bbls of 1.9 SG cement slurry, the cement was displaced by 86 bbls of water

- The DV was closed with 1750 psi.
- A cement top-up job was performed in the annulus by pumping 50 bbl. of 1.9 SG cement slurry with no return.

Loss zones and plugs used to treat it are summarized as following:

Table 6. Summary Of Losses Zones & Treatment

HOLE	ZONE m	No. OF PLUGS	PLUGS VOLUME bbl.	CEMENT tones	OTHER PLUGS
17 1/2"	66-72	3	95	19	
	104-175	2	65	13	
	333-356	4	223	45	
	374-381	8	414	84	
	TOTAL	**17**	**797**	**162**	
12 1/4"	370-409	14	467	95	+189 bbl. GUNK (5 PLUGS)
	470-498	4	82	17	LCM
	580-610	3	74	15	LCM
	680-720	8	232	47	
	760-815	6	178	36	LCM
	832-840	4	123	25	LCM
	868	2	70	14	
	940-970	11	275	56	LCM
	978	1	40	8	
	995-1009	12	377	77	+50 bbl. GUNK, 2 CMNT PLUGS WITH CEM-NET
	1026	1	52	11	
	1055-1056	2	105	21	
	TOTAL	**68**	**2075**	**390**	
GRAND TOTAL		**85**	**2872**	**553**	

2.2 Case Study

In Argentina, specifically in the Neuquén Province, the fields are known for having a high formation pressures and influxes while drilling the reservoir. Some of the challenges faced while drilling with conventional method are kicks, drilling fluid losses, instability of the wellbore and formation damage.

Also known for difficulties during cementing operations. These well constructions problems have a significant contribution to the Non-Productive Time (NPT). An Implemented technology called Manage pressure cementing (MPC) has been used for some recent wells. The challenges were faced during well construction operations were are able to have a significant increase in the non-productive time (NPT).

The results of applying these technologies were positive, a successful implementation was obtained based on that there was as following:

a significant change on the well geometry profile in a way that a lower density drilling mud was able to be used without having any problems caused by the heavier mud in the upper suctions.

The Operational window is varying in each well and a different fraction pressures, causing some difficulties while dealing with them using conventional methods, the ability of constantly changing the SBP by the MPD systems, made it simpler to deal with the variation of pressures in the well while keeping the required bottom hole pressure.

Managed Pressure Casing Drilling had a significant result with controlling the influxes while drilling, the increased annular frictional pressure losses gave and important advantage while controlling influxes. No wells required increase in drilling fluid density while using MPCD or shut in a well for influx related matters.

2.3 Results

MPCD had a successful implementation in Argentina's projects that they were applied in. The increased frictional pressure losses in annulus provided a safer and time reduction in drilling operations compared to conventional drilling (Figure 3). MPCD gave the ability to deal with influxes without any shutting in well or changes in drilling fluid parameters. In some of the projects that MPCD was chosen as the drilling method, up to 53% time reduction was experienced and others between 30-38%, compared with traditional drilling with MPD. The figures 5 and 6, illustrates the time-depth diagram for MPCD with MPC and Conventional Drilling with MPD.

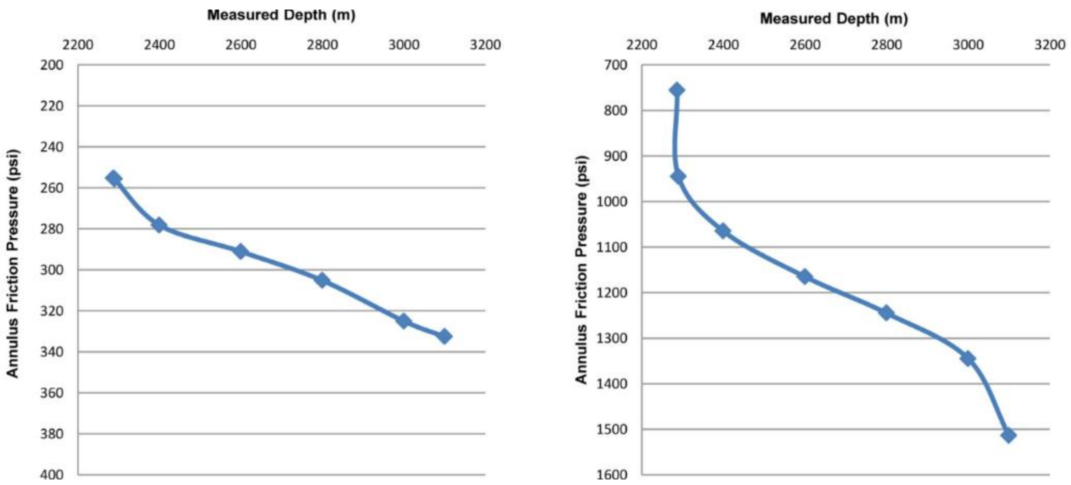


Figure 3. Annular friction pressure losses: (left) drilling using DP and (right) drilling using MPCD.

well drilled using MPCD and the other with MPD and conventional DP.

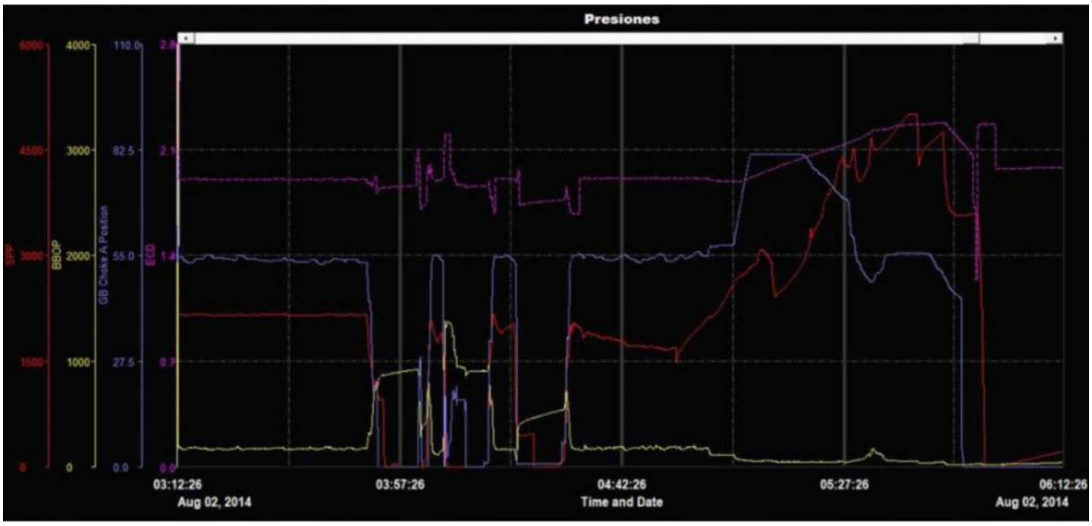


Figure 4. MPC performed in automated mode.

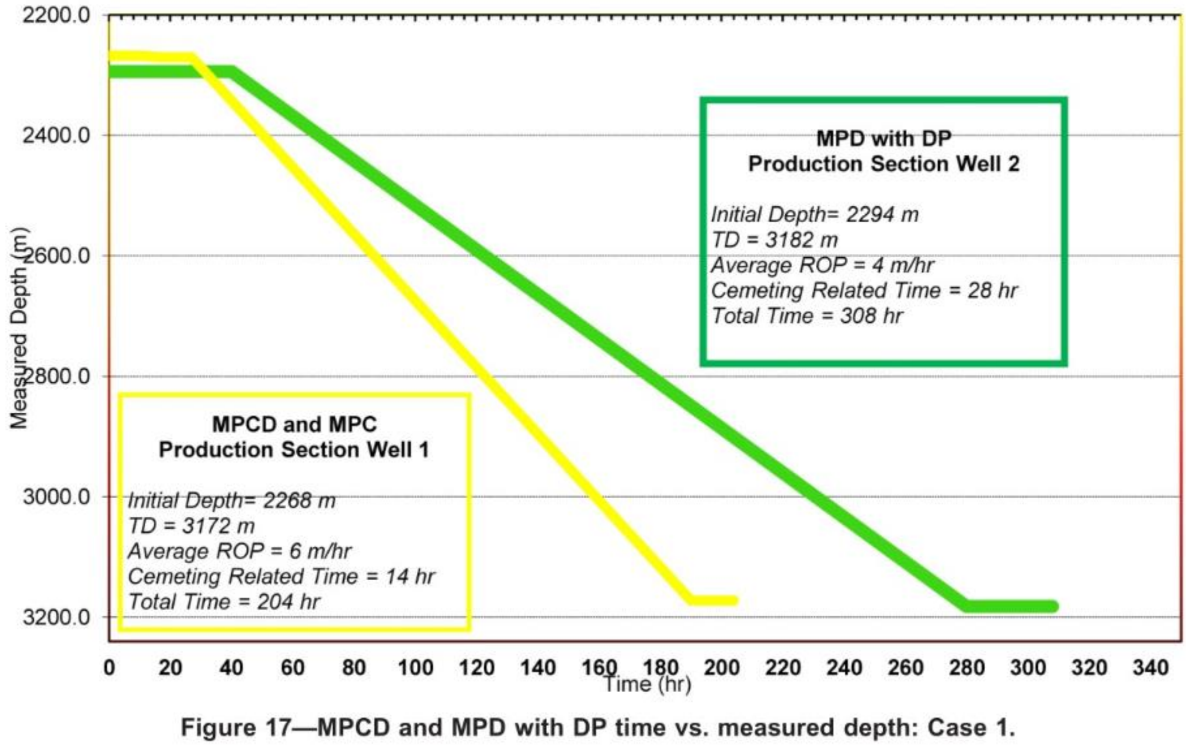


Figure 5. MPCD and MPD with DP time vs. measured depth: Case 1.

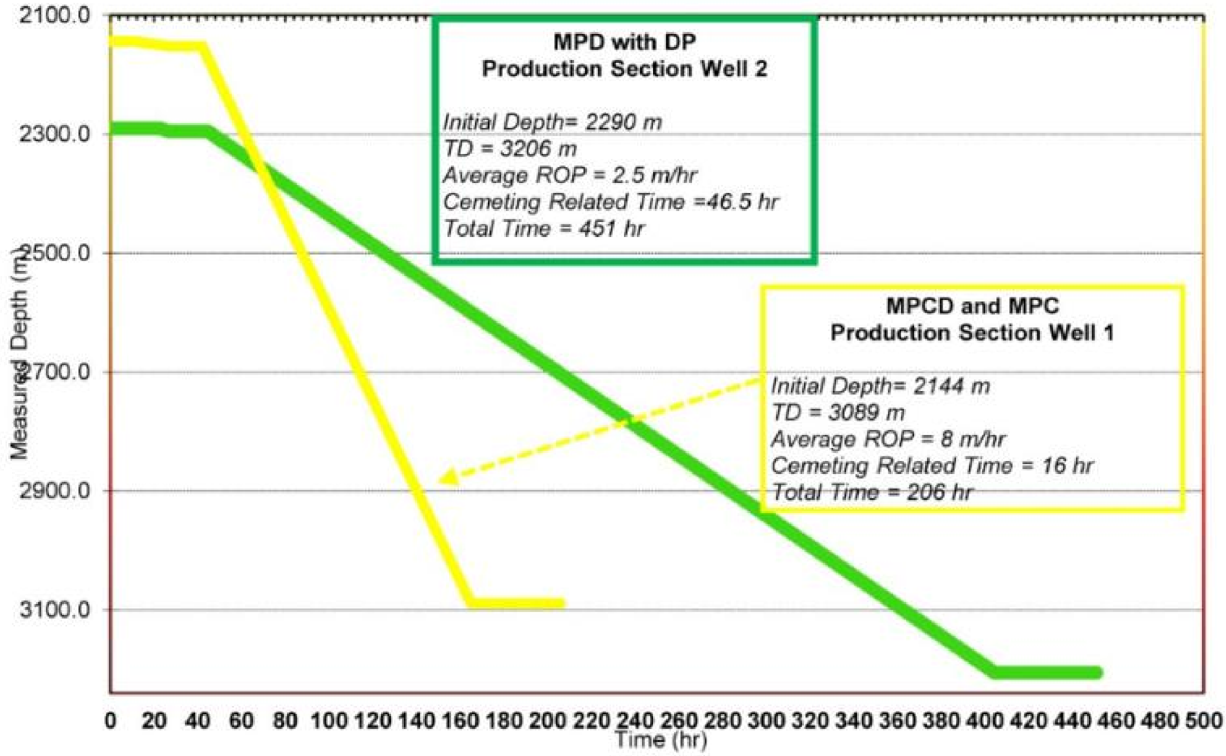


Figure 6. MPCD and MPD with DP time vs. measured depth: Case 2

2.4 Case Study Conclusion

The implementation of MPCD had an impact on pressure window controlling while drilling through weak zones or depleted pressure zones. The increased window pressure control in the parts that are exposed in openhole gave the ability to have fewer casing section of 3 instead of 4. Also, economical wise it proved its advantages when being applied in the problematic fields which in normal cases it not recommended due to the increased operation cost rates.

Chapter 3 Managed Pressure Casing Drilling

3.1 Overview

The Managed Pressure Casing Drilling (MPCD) blend combines the most powerful and efficient value added by MPD and Casing Drilling technologies to reduce weaknesses the techniques sometimes have when used individually. In essence, together they are greater than parts – parts already proved their value, by being on the top of technology. Normally, Casing Drilling technology can cancel casing running operation, but still various of conventional drilling hazards could be increased such fluid loss, stuck pipe and formation ballooning are increased but the reduced annulus space and a relevantly high ECD at a required pump rates compared to conventional drilling method.

Similarly, MPD with drill pipe still suffers from many of the same problems that plague conventional drilling techniques. Based on the depth of the hole, drilling fluid weight, fluid rheology, the increased annulus space between drill pipes and wellbore, can cancel the ability of mud pumps to generate enough ECD in order to control pore pressure in the open hole. Thus, the operation becomes more dependent on mud weight and its effect on hydrostatic column. Managed Pressure Casing Drilling mix reduced annulus gives the ability to operate with lower drilling fluid density giving a higher range of control in open hole which are connected to MPD parameters. Drilling fluid rheology, hole geometry, SBP and pump rate can be manipulated to extend and control pressure profile instantaneously. As a consequence, an extension of casing seating depth may be done.

In order to have a successful Implementation of Managed Pressure Casing Drilling, driller must recognize the locations of the permeable and Impermeable rocks. To avoid collapses in borehole, failure mechanics of exposed rocks shall be taken in consideration. The Pore Pressure of a permeable rock should be also taken in consideration based on the intent of the drilling operations. Influxes must be controlled with balanced or overbalanced equivalent hydrostatic column. Based on strength and collapse issue of wellbore rocks, the pressure margin may be fixed at the drilling bit in order to allow for less overbalanced stress on weaker rock in the upper parts of the open borehole section.

An appropriate Managed Pressure Drilling parameters can affect the adjustment. Controlling pressure in the upper exposed parts of the rock which are weaker than below parts can be the most influencing aspect of reaching a deeper or eliminating the casing seat. A good Managed Pressure candidate is considered by pore pressure values and rock strength below casing shoe in open hole, and if the difference in pressure could be controlled. Collecting precise data about pore pressure and fracture pressure is needed which can be done by pore pressure analysis from log data, seismic data, etc. LOT and FIT may be performed to confirm Fracture gradient profile when reaching casing seat depth. A robust computer modelling software is also essential to a precise downhole hydraulics plan

3.2 Managed Pressure Drilling Technology

3.2.1 Managed Pressure Drilling (MPD)

Managed Pressure Drilling (MPD) started as an essential technique for drilling wells with narrow pore pressure, fracture gradient window. The main odea is to precisely control pressure in the annulus to stay within the acceptable range between minimum pore pressure and maximum of fracture pressure. By controlling and managing the annular pressure profile, MPD uses many different tools and equipment, including hardware and software, to mitigate both costs and risks in the wells with narrow mud window. Such technique uses a backpressure controller, density for drilling fluid, drilling fluid rheology, drilling fluid level in annulus, circulation friction and the borehole geometry.

During managed pressure drilling, it is necessary to make a proper seal around the drill string while rotations to keep the hydrocarbons or formation fluids inside the well and prevent their release to the atmosphere. As mud weight window is, basically, narrow in MPD and the risk of getting kick is high, the device of providing back-up pressure is also required. Beside of that, the kick must be recognized and taken action and a special equipment is existed for this purpose.

Conventional overbalanced drilling uses atmospheric pressure acting on drilling fluids on order to create equivalent circulating density (ECD) that leads to a pressure in bottom hole higher that pore pressure (purple line) but not exceeding formation fracture pressure (red line) that are being drilling in. Figure 8 compares OBD (Green), MPD (Yellow) and UBD (Blue).

Technically, MPD is similar to Underbalanced drilling method (UBD). There are lots of common tools using for both methods. The most significant disadvantage of UBD is damaging the reservoir which MPD solves it by managing the bottom hole pressure. As well, the risk of getting influx in UBD is much higher than MPD if the pressure of the fluid in the well falls below than the pore pressure. MPD can provide extra pressure that calls "back-up pressure" using back-up pressure devices. In the other word, MPD manages the pressure to remain between the pore pressure and fracture pressure of a reservoir or a formation at any specific depths. Besides, it is set up to handle the influx of fluids that may occur during drilling but does not actively encourage influx into the wellbore.

With a wellbore pressure profiles being controlled precisely. showings and mud losses determination are virtually instantaneous. Rig crew and equipment safety during everyday drilling operations is increased. Thus, a reduction drilling operations costs and reduced NPT that are related to drilling.

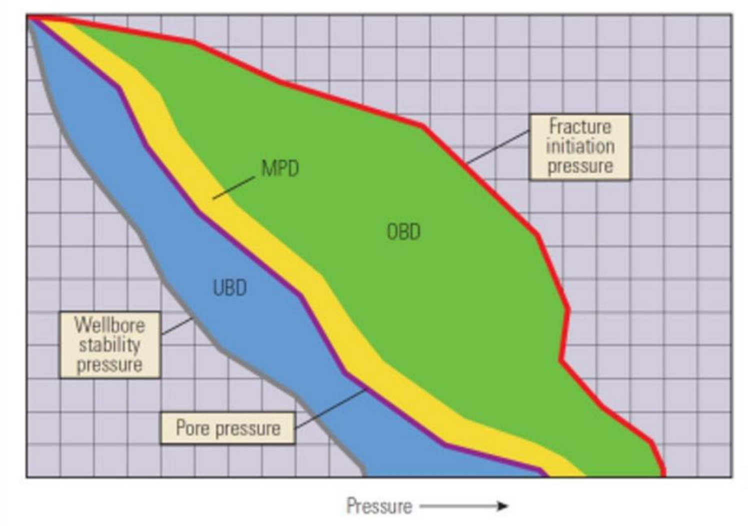


Figure 7. OBD, MPD and UBD Pressure vs. TVD

3.2.1.1 MPD Advantages

The main goals of MPD are to mitigate drilling problems and improve operational drilling efficiencies by reducing NPT with special techniques and surface equipment. In deep water drilling, many projects would not be economically viable without MPD techniques.

Refer to researches have been done in the Gulf of Mexico (GoM) between 1993 to 2003 for gas wells, about 40% of NPTs are related to pressure-related issues during drilling. These problems are included lost circulation, kicks, and wellbore instability. The advantages of MPD are shortly explained as below:

1) **Extending the Casing Points:**

During well planning phase prior to start drilling, each casing shall be predetermined about the depth of casing running, many factors are being considered to determine this point for each sector. Mud window is from the main factors, minimum value would be the pore pressure and maximum value is the fracture gradient, both plotted together, thus, from bottom of the plot, bottom of the borehole should not be greater than the maximum value (fracture gradient) and also not being less than the minimum value (pore pressure). This situation leaves no other options except that whenever the bottom hole pressure exceeds the allowable maximum value, run casing to strengthen then upper parts of the wellbore, so that drilling can be resumed without exceeding fracture gradient while using new drilling mud that could cause problems if was used without running casing first. Managed pressure drilling technology gives to the ability to manipulate the bottom hole pressure in a way that allows to continue drilling operation to a lower point without having any problems. This casing extending point results with a reduced casing string requirement in wells, thus it can be a major economical solution in case used in needed projects. Figure 9 and 10 illustrate that how MPD can eliminate casing string. Conventional drilling requires seven casing string sizes while MPD reaches the target by only three casing string.

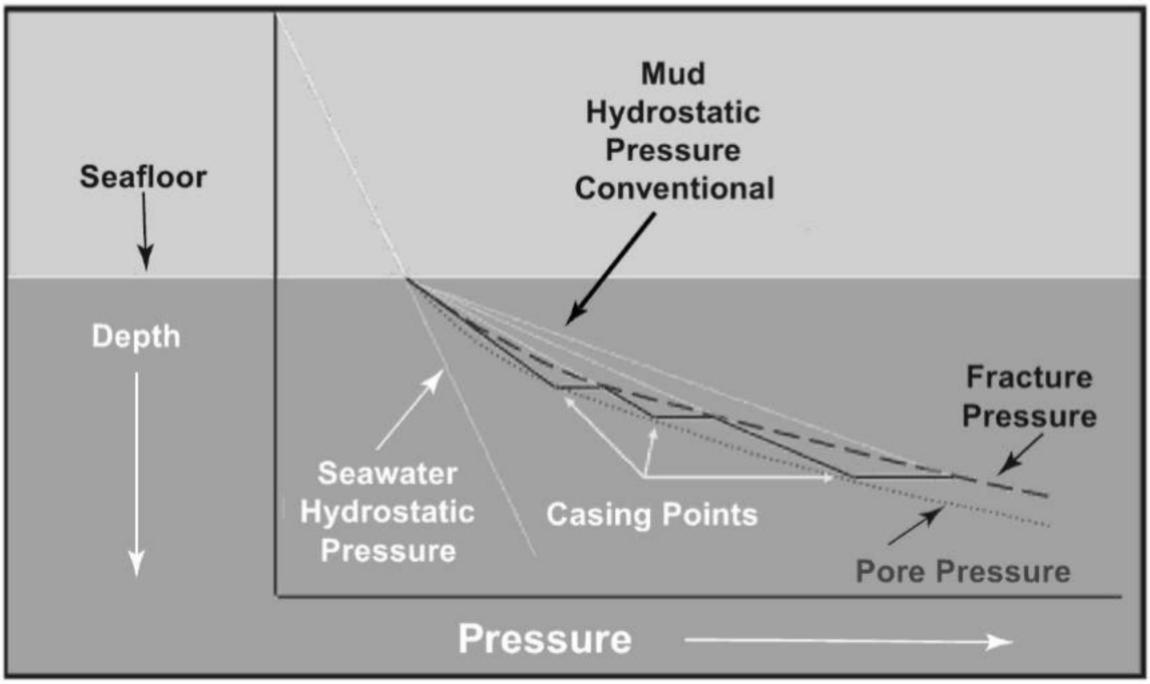


Figure 8. Using MPD techniques to reduce the required number of casing sizes

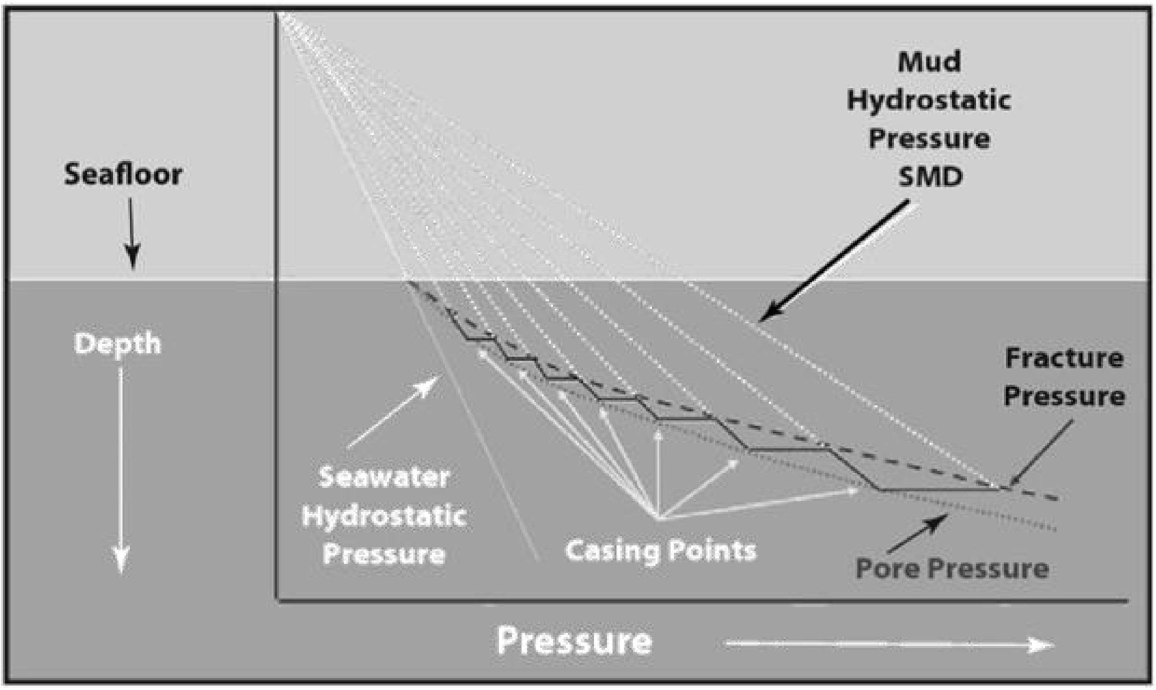


Figure 9. Conventional drilling requires seven different casing sizes

2) Lost Circulation

Lost circulation usually occurs when the mud density becomes exceeder than formation fracture pressure. This phenomenon causes making fracture inside the formation/reservoir and due to higher mud density rather than the formation pressure, the mud starts to be infusing inside the formation which is called "Lost Circulation". With Managed Pressure Drilling, keeping the drilling mud density less than fracture pressure while using annular back pressure at surface, give the ability for the operator to keep wellbore pressure within the acceptable range between pore pressure and fracture gradient.

3) Well Kick

Well kick occurs when influxes enter the well due to the pressure found within the drilled rock is higher than the drilling mud hydrostatic pressure that acts on the borehole or rock face. In this situation, the formation higher pressure forces the fluids into the well. This forced fluid flow or influx is called a kick. Even if the kick is detected and controlled and killed in the proper time without any difficulty, there are plenty of costs for time and mud materials used. Managed Pressure drilling aims to avoid the control the well when kicks occur by monitoring ECD in the well and inflow and outflow control and any changes of pressure in the wellbore with surface back pressure. (Managed Pressure Drilling. Gulf Publishing Company. Houston, Texas. 2009).)

4) **Differentially Stuck Pipe**

In any case, stuck pipe is an expensive issue. This type of stuck pipe happens when the drill pipes in the well are being pushed towards the permeable formations due to the differential pressure between hydrostatic and formation pressure. Drill string sticks to the mudcake formed on wellbore permeable layer walls during drilling operation leading to increased friction that will make pipe movement hard or stopped. As the large literature volume and computer programs specialized to this certain problem has evidenced it. Due to this, usually a kick is faced as result of pipe sticking. MPD decreases a differential pressure between the formation and the wellbore that causes reducing the risk of differential stuck pipe.

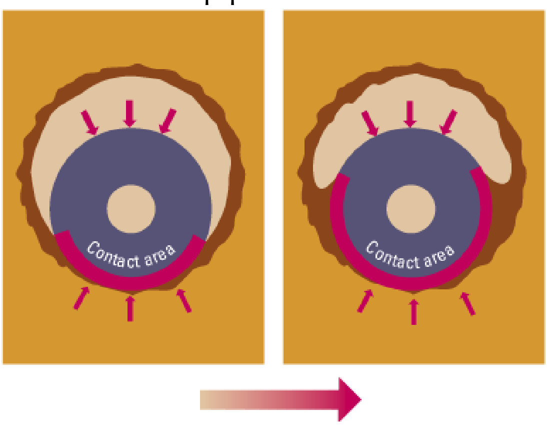


Figure 10 Differential Sticking (https://glossary.oilfield.slb.com/)

3.2.2 MPD Modes and Methods

3.2.2.1 Reactive/Proactive MPD Categories

The International Association of Drilling Contractors (IADC) has defined MPD further by creating two categories:

Reactive MPD has the drilling programs that are applied with the chokes, Rotating Control Device (RCD) and could be drill string float, for a safer and more efficient problem handling, that may occur in the borehole. The reactive managed pressure drilling uses the MPD methods to overcome drilling problems when they occur. Usually, the is well planned conventionally, and only when in need in unexpected developments, the MPD systems are activated. Reactive Managed Pressure Drilling projects, aren't an in-situ decision. Only few cases are applicable since that the nature of small projects can be overcome without the need of applying MPD because of cost efficiency aspects.

Proactive MPD also used managed pressure drilling equipment to allow to actively manage the pressure through the exposed wellbore. Which includes the casing and drilling fluid and wellbore design to precisely manage the pressure profile. This approach uses the full range of the tools in order to have a better control of well placement and casing seating depth, with reduced number of casing strings, the improved drilling fluid density requirements and cost, also providing better control of pressure for advanced well control problems detecting and warnings. All combined lead to more efficient drilling time and reduced NPT. In short, proactive MPD can drill operationally and economically challenged wells and undrillable wells.

3.2.2.2 Constant/Variable Bottomhole Pressure Classifications

A useful drilling technology is the one that provides a solution for a real-world problem in a cost-effective manner. Managed pressure drilling technology connects to the conventional method equipment and enhances the capability of them. The capability of the drilling fluid and the circulation system, two basic elements that can be found in any drilling method uses to control bottom-hole pressure, is improved by MPD techniques. However, when time passes with production, pore pressure, well bore stability, and the fracture gradient could change to the point where more dynamic control is in need.

From all the different processes and technologies needed to successfully drill a well, the ones that controls the bottom hole pressure (BHP) comes in first. Geology and in-situ pressure determine the boundaries within which drilling must regulate the BHP. Regardless of the geology and pressure with which drilling must contend, a drilling system's primary tasks, such as transporting the cuttings, preventing influx and losses, and keeping the drill pipe free, the hole open, and the well finished on target and budget, are the same. Those tasks never change as time passes on, they just more complicated to overcome.

The compile of pressure control methods referred to as managed pressure drilling (MPD) enhance the performance of basic elements by adding more control to the BHP while drilling, more control over BHP to operational phases when the rig pumps are shut down, enhancing wellbore stability and maintaining well control.

The Different methods of managed pressure drilling differ in significant ways and not all are applicable in all situation and fields.

The constant bottom-hole pressure refers to a process where the annular pressure in a well is held constant or almost constant at a specific depth, regardless if rig pumps on or off. In this context, constant means maintaining BHP within a window where there is an upper and lower pressure limit. The difference between these limits is also known as the margin. Where the lower limit is pore pressure and the upper limit is fracture pressure, lost circulation and differential sticking.

Continuous Circulation System (CCS)

Continuous Circulation System has the advantage of the elimination of reducing the bottomhole pressure during connections. In conventional drilling, the driller must turn the mud pump off for making a drill pipe connection for further drilling. By using this method, it is possible to keep the bottomhole pressure between pore pressure and fracture pressure while the driller has turned the pumps off for making a connection. A steady equivalent circulating density (ECD) can be achieved with this technique. Additionally, the technique minimizes the positive and negative pressure surges during making connection in the conventional drilling. The benefit of the technique is to improve hole-cleaning, have better wellbore stability, shorter connection time, and eliminate of gas kick connections.

In a narrow mud window, when the mud pumps stop, it is possible to ECD become lower than pore pressure and then, formation fluid can enter to the wellbore. In the other hand, there is risk of collapse formation and stuck pipe while the ECD is lower than pore pressure. When connection is completed and the mud pumps turn on, the pressure usually increased to break the mud gel. This increasing pressure is called “pressure spike”. Pressure spike can cause lost circulation which is one of the most important reasons of kick or blowout. The system that is explained here is from NOV. Each company has different method and system. In order to perform the technique, a CCS unit must be installed in the rotary table. The coupler can be divided into two different upper and lower sections (Figure 11).

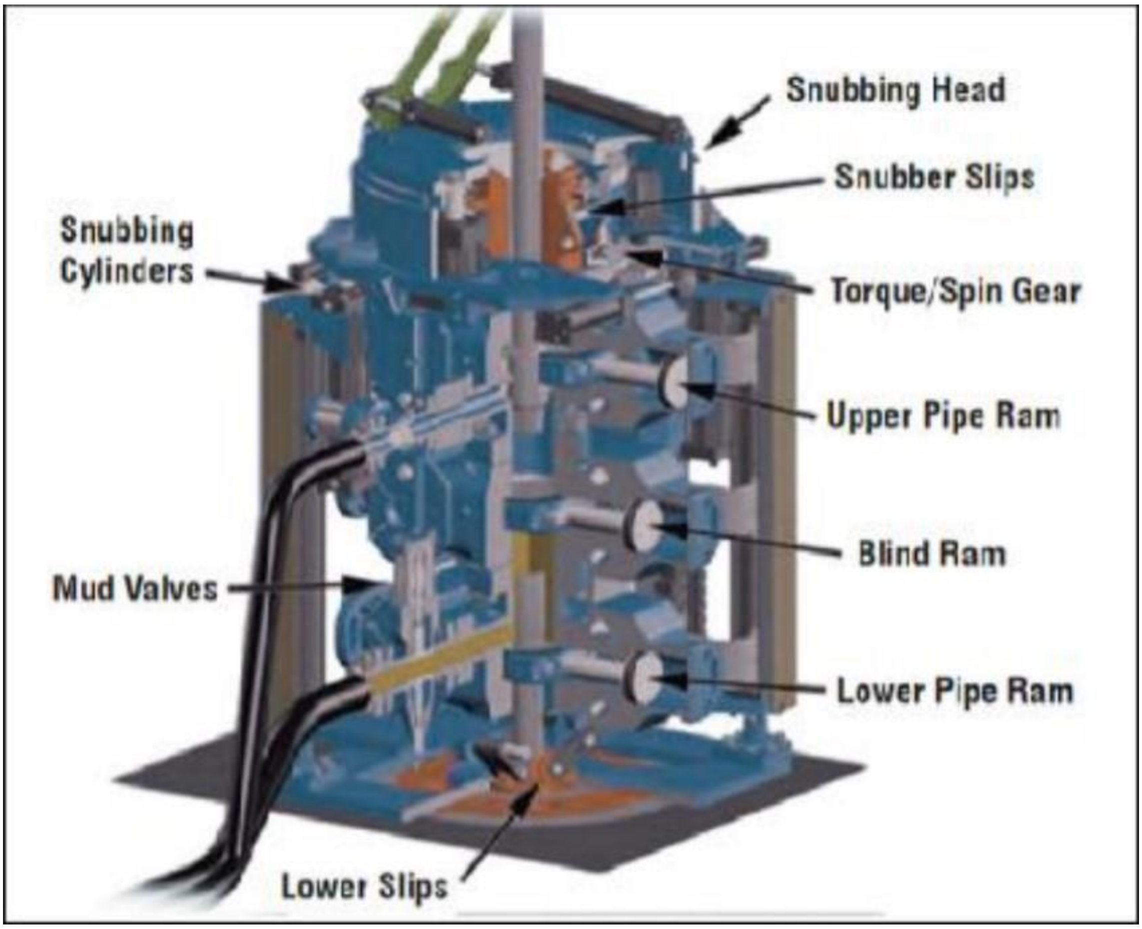


Figure 11. NOV CCS Unit

For making a new connection, the tool joint has to be between the lower rams and upper rams of the CCS unit. Then, both upper and lower rams are closed around the drill pipe. The pressure chamber between two rams is open and filled with drilling fluid at circulating pressure. The next step is to break and spin out the connection by hydraulic motor in snubber installed in the unit. When the connection is broken out, there are two flow paths for circulating drilling fluid into the open tool joint box inside the unit. One via standpipe and top drive and the other is from the diverter manifold. The pressure from standpipe must be shut off and blind rams inside the unit must be closed which isolate the lower half the pressure chamber. Pressure fluid from upper chamber is now bled off to mud pit and the upper pipe ram is open and prepare for picking up the new drill pipe stand. The new stand lower down close to blind rams and then, the upper pipe ram is closed around the pipe and the upper chamber starts to be pressure up through standpipe in order to have an equalized pressure in two chambers. When the pressure is equalized, the blind rams is open while the simultaneous circulation existed through standpipe and diverter. Then new stand is made on the previous box tool joint stand and torqued up. The pressure in chambers is released and drained into mud pit and both upper and lower pipe rams are opened and drilling resumes by circulating from the standpipe and top drive inside the string.

Dual Gradient Drilling (DGD)

In general, Dual Gradient Drilling refers to drilling with two different fluid density gradients. It mostly uses in deepwater drilling operations where a long riser contributes a significant hydrostatic pressure. For example, more drilling mud is needed to fill the increased raisers length, it can go up to 3700 bbl. for 10000 ft of length with a 19 ½" diameter. Increasing the synthetic-based mud fluid required. (Managed Pressure Drilling. Gulf Publishing Company. Houston, Texas. 2009).

Due to the weak strength zones, conventional drilling application in deepwater usually need more casing strings in order to avoid lost circulation in shallow depths while using same drilling fluid. The concept of dual gradient drilling is using two different fluid density gradients in order to not exceed the fracture pressure, especially in narrow mud window situation. Dual gradient drilling uses a lighter mud in upper sections of the well and a heavier mud in lower sections. Which allows the pressure to stay in pressure window within Pore pressure and fracture pressure. Figure 12. Dual gradient drilling gives the ability for operators to control pressure profile in order to prevent surpassing fracture pressure while also not going below pore pressure.

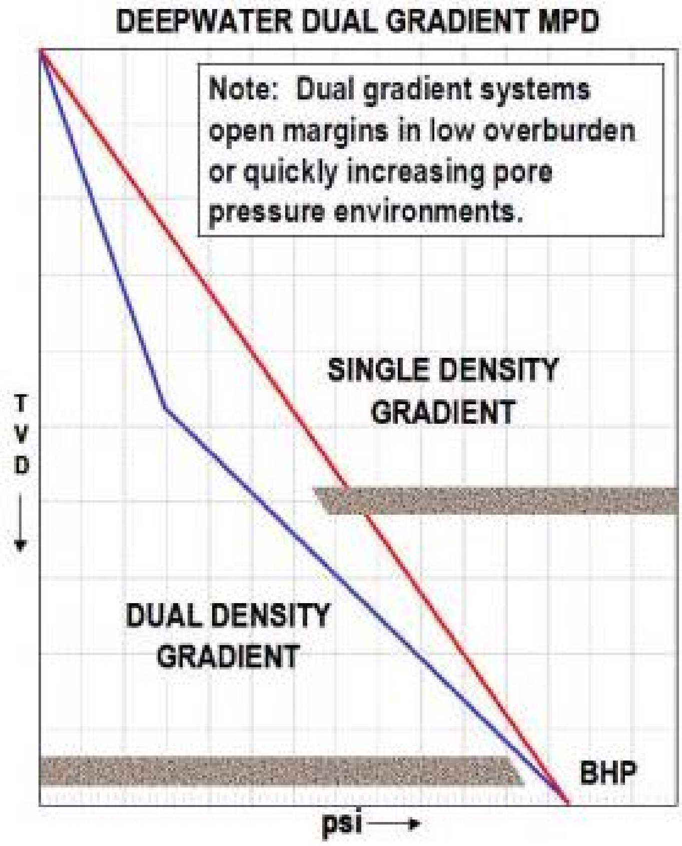


Figure 12. Dual Gradient Drilling Pressure Gradient Profile

Three different techniques of Dual Gradient Drilling method are discussed in this section:

Controlled Mudcap System

In mud cap drilling MPD mod, both mud and water are used down the well bore and drill pipe to have control over the drilling mud losses occurring and eliminate kicks from occurring while drilling in fractured or highly fractured formation or in a layered formation with different pressure regimes. This mod decreases the time needed to overcome these problems and cost of this time and material used with continuous well control issues and loss of drilling mud. Mud cap drilling was developed to decrease time and mud losses exerted by the circulation loss. In simpler form, heavy mud is pumped (bullhead) down the annulus until the well goes to a vacuum. Drilling operation is then resumed, using fresh water to be pumped down the drill string without any returns to the surface. A float is run in the pipes to eliminate any backflow.
The generated cuttings from the drilling operation goes to the fracture or fractures that are causing the drilling mud losses. (Managed Pressure Drilling. Gulf Publishing Company. Houston, Texas. 2009)

Pressurized Mudcap Drilling

Pressurized Mudcap Drilling (PMDC) is the most common method of MPD which helps in drilling through highly fractured formations and zones with severe lost circulation problems. It is also can be called "light annular mudcap" or "Closed-hole circulation drilling".

The first usage of this method happened in Austin Chalk fields in Texas. The concept of the method is using a combination of two drilling fluids, a low density and a high-density pressured mud column. The low-density mud should be preferably inexpensive, such as seawater in offshore wells. This mud is pumped down through drill string and drill bit and carries away the cuttings into the fractured zone. A heavier mud referred to as Mudcap, is located in the annulus above the fractured/trouble zone. The mudcap provides the required hydrostatic pressure to maintain bottom hole pressure and prevent the well from a kick. (Mathew Daniel Martin. Texas A&M University. May 2006). The annular pressure is monitored during the PMDC and if the pressure increases, it means the hydrocarbon starts entering into the annulus and then, more mud is pumped into the annulus to restore to original borehole pressure and preventing a kick. (Figure 13).

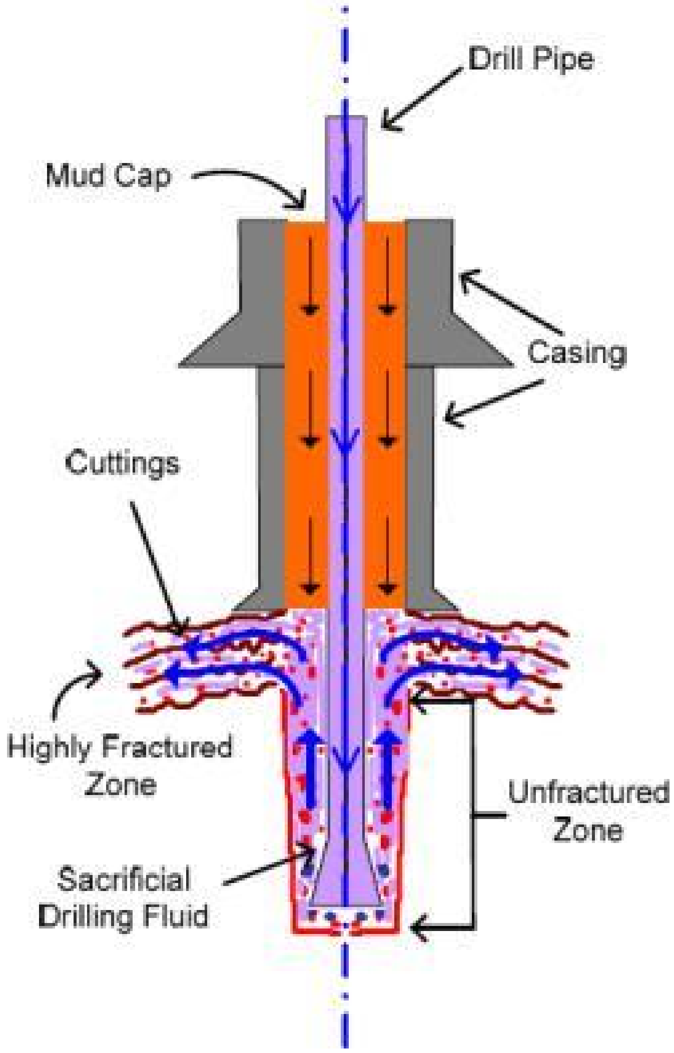


Figure 13. Pressurized Mud Cap Operation

PMCD provides the following advantages:

- Overcoming trouble zones that would be risky to drill through without PMCD.
- Reducing costs since significant amounts of drilling fluid is saved that would have been lost.
- Increasing Rate of penetration since lower mud density is being used in drilling operation.
- NPT cutting down that would have been huge connected with trouble zones.

Figure 14. Illustrates PMCD pressure profile, lighter fluid used in drilling and more dense or heavier fluid applying pressure so that the lighter fluids enter the loss zones. All light drilling fluid or influxes are being forced to go to the depleted zones. Giving the ability to maintain control of the well even with complete circulation loss. (Managed Pressure Drilling. Gulf Publishing Company. Houston, Texas. 2009).

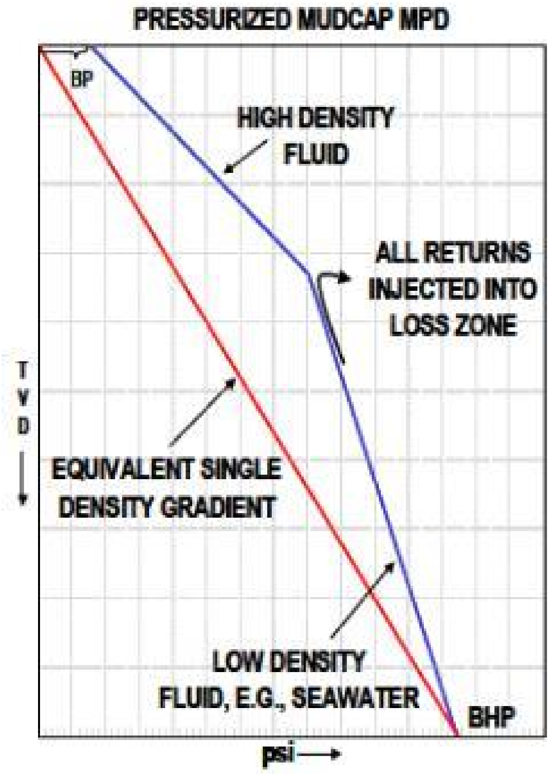


Figure 14. PMDC Pressure Profile.

1. **Losses Evaluation**

When mud losses start occurring, severity and cause of the should be evaluated in order to decide the appropriate steps to be taken. Some pointe needs to be considered prior to consider switching to PMCD, such as:

- weather losses are due to the use of an improper mud weight, or a fracture is encountered.
- If losses can be cured with traditional treatments (LCM).
- In case if the PMCD is applicable in the given case, what is the perfect light annular mud weight to conduct operations with safely.
- Regardless if there is vertical permeability between losses and other permeable layers. Underground blowouts can occur if geological if there was no place for fluid to go such as permeable zones or fractures after a while of injecting the sacrificial drilling fluid and bullheading cycles. The permeable zones can work as a path for sacrificial fluid to enter.

2. Fluid Selection

The same as in any drilling operation, drilling mud has a straight effect on the success of the operating. Sacrificial fluid job is same as normal drilling mud except for cuttings transporting will be to the loss zones rather than to surface. Surly the mud should be cheap since it is meant to be pumped down with no returns. Thus, logistic side should manage enough water to perform operations. The chosen Mudcap should fulfil its requirement by not causing any damages to the well or damaging emulsions, also being able to be weighted up quickly in case it was not enough to perform as a cap, and surely being economically viable.

General aspects of Water based Light Annular Mud (LAM):

- Easily prepared and disposed.
- Less expensive.
- Higher gas migration rate since there is no solubility;
- Risk of hydrate formation in deepwater operations.

General aspects of Oil-Based Light Annular Mud (LAM):

- Hydrate inhibition;
- More expensive;
- Lower gas migration rate.

Floating Mud Cap

Floating Mud Cap is the oldest yet simplest mud cap mode is the floating mud cap. As simple as it sounds, drilling operations are conducted normally until fluid circulation is lost, at which point drilling continues without any returns to the surface. The fluid level "floats" to some point or level depending where it balances the formation pressure in the lowest pressured fracture faced. In case in need, fluid is injected into the annulus to keep the well on a vacuum. In cases where reservoir pressure is low enough and where an enough supply of water is available, the water can be continuously be injected into the annulus to keep well control. This in particular is common when working on depleted gas wells that causes heavy fluid losses in. As long as fluid is injected into the annulus fast enough to carry migrating gas and produced fluid back into the formation, the well will not face any kicks. Fluid velocity in the annulus can range from 400to 5400 ft/hr with typical velocities being in the range of 1000–2000 ft/hr. (Managed Pressure Drilling. Gulf Publishing Company. Houston, Texas. 2009)
Continuous annular injection is applicable in case time required to complete the work is short or unlimited kill fluid (which is usually water) is in reach.
few surface equipment is required, thus, a simpler rigup and only a pump and an RCD may be in need, unless high reservoir pressure that could require a high-pressure pumping equipment and replacement of the rig's standpipe and mud lines with those having a higher-pressure rating.
In some of the cases, it was not possible to eliminate the losses. Even if it is possible to seal up the fractures of the loss zone with (LCM), cement, or other materials, these fractures are the primary production conduits, so plugging them cancels the main idea of drilling wells in the first place.

3.2.3 MPD Equipment

For managed pressure drilling operation, a sets of surface equipment and downhole tools are required. Same as conventional drilling, technical specification of the equipment and tools is related to the well pressure, temperature (HPHT), the environment (H2S) and etc. In this section, the most important equipment for performing MPD:

3.2.3.1 Rotating Control Device (RCD)

Is surface equipment that gives the ability to manage pressure during drilling operations in order of making a seal around the drill sting. It needed to withhold well fluid or hydrocarbons from being released to the atmosphere.

The device has a stripper rubber which is smaller than outer diameter of drill pipe; this rubber makes a seal around the drill pipe while there is no hydraulic pressure behind that. Due to conical shape of the sealing element, by inserting hydraulic pressure behind the element, it will better seal the drill pipe.

3.2.3.2 Choke System

Choke system has vital function in regulating bottom hole pressure. A choke system consists of various manual and/or hydraulic valves, manifolds, and control units. A choke system can be operated locally and/or remotely as well as manually and/or automatically. Bottom hole pressure will be adjusted by opening and closing the choke valve. Closing the choke valve causes increasing the bottom hole pressure and vice versa.

Choke working pressure is related to the well pressure. In offshore deepwater drilling, the 15,000-psi working pressure usually is used.

3.2.3.3 Non-Return Valve (NRV)

During MPD, the backup pressure is added to the system from annulus. In order to prevent mud flowing back through the drill pipe, it is necessary to install NRV inside the drill string. Because the drilling mud contains cuttings and the risk of plugging inside the drilling string or damaging MWD tools is high. The NRV valve is generally named Float valve which has two main categories: Flapper type and Spring type.

3.2.3.4 Kick Response and Influx Management

In conventional drilling, the kick is identified by monitoring the mud pits level; in case of any sudden increase of mud pit level, shut-in procedure must be performed. In MPD, because of lots of changes in mud pit level, it is hard to identify kicks by the tradition method. As MPD is mostly used in narrow mud weight situation, it is necessary to have a kick response and influx management system in order to earlier kick detection and faster taking action. A set of surface and downhole sensors as well as pressure gauges is used in this regard.

3.2.3.5 Backup Pressure Compensation Device

The backpressure compensation device consists of electric triplex plunger pump, AC motor, suction line, discharge line, high density mass flow-meter, etc. The backpressure compensation device can carry out flow compensation during circulation or pump stoppage. The device provides necessary flow rate to throttle valve working. The device can circulate for long and compensate for system flow rate during MPD operations. The device maintains the flow rate needed for wellhead throttling and the best throttling function of the throttle valve.

3.2.3.6 Downhole Pressure Measurement (PWD) Tool

The PWD tool is a crucial component for the managed pressure drilling system, which provides downhole readings and transmitting the data for the purpose of creating a real time hydraulic calculation software, hence, modifying the hydraulic calculations model to be more efficient for the MPD system. The main parameters that the tool has to measure includes

- In-string/Annular pressure
- Temperature
- Inclination, Azimuth and Tool Face (Integrated with MWD system)

The performance of the system is depended on Data Transmission Rate, Continuous Working Time, Sampling Interval, and Maximum Working Temperature.

3.2.3.7 Conclusion

Adding Managed Pressure Drilling (MPD) technology provides access to sophisticated monitoring system, which could be used to help with data collection and recording, which can be turned to information about pressure regime and the formation being drilled. Thus, problems might occur could be detected earlier and avoided sooner.

The ROP improvement is an added value also when MPD technology is being used, since MPD has the potential to improve the rock cutting cleaning leading to a better hole cleaning and thus, reducing the probability of bit balling.

While using MPD, a reduction in differential pressure occurs, which can help in reducing the probability of differential sticking issue.

3.3 Casing Drilling

3.3.1 Casing Drilling Concept

As it is called, this technology dose the drilling operations using casing pipes instead of drilling pipes, which helps us avoid some of drilling problems that may or expected using the conventional drilling. Casing drilling technology was implemented in many cases in different countries as a solution to reduce the overall costs and time of drilling operations and problems related to drill pipes faced during conventional drilling well construction. In addition to reducing time due to the reduced tripping operations. The events or problems occurring during tripping operation can lead to a less efficient and in worst case scenario, losing the well. It is a proven fact that the reduced time due to some tripping operation eliminating, there may be a more efficient factor which is avoiding the problems that may happen with tripping operation. There are many case scenarios where hazards such as lost circulation, well control problems and stability of the wellbore are affected by tripping operation of drill string or problems like stuck pipes where the movement of the string is not possible. Since CDS has the ability of continuous fluid circulation, it provides increased safety while leaving the well stating without a means of circulating drilling fluid while drill string is tripped. The eliminated tripping operations with CDS reduces the surge and swab pressure differences.

The Two methods of casing drilling technology are:

- A latched retrievable bottom hole assembly inside casing pipes, that has a motor to operate the conventional drilling bit and underreamer.
- Non-retrievable casing system that are rotated from the surface with a special casing drilling drillable bit and cemented in place bottom hole assembly

The casing drilling technology was primarily designed for multi-well offshore platforms, onshore multi-well projects, deep water projects and situations where problematic formations are expected that would require a lot of time and risk increasing to overcome more.

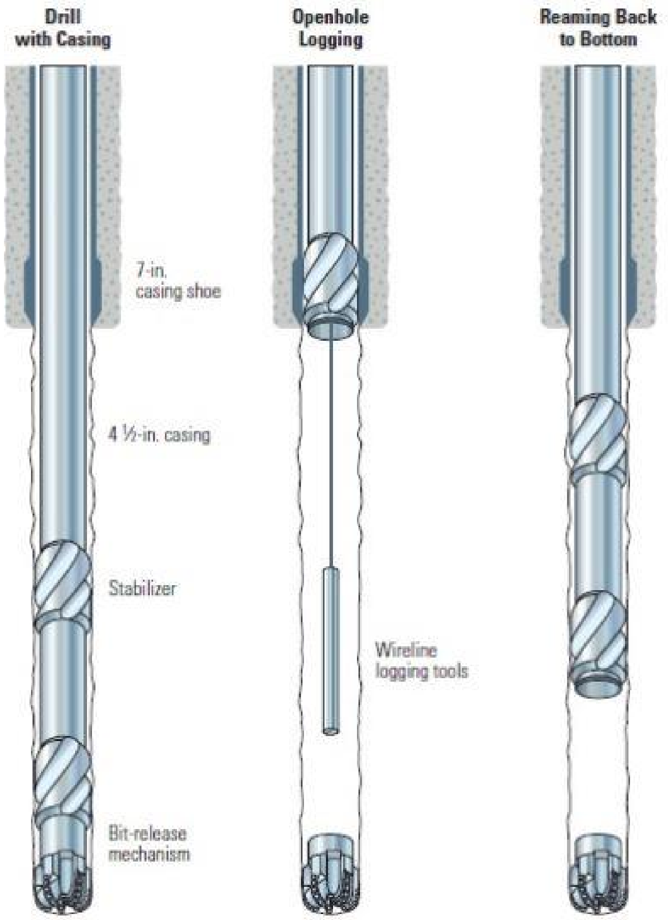
- latched retrievable BHA inside the casing that incorporates a motor to drive a conventional bit and under-reamer or
- Surface rotate casing system incorporating an Internal Casing Drive System and a drillable “cemented in place” drilling Bottom hole assembly.

Casing drilling system has been designed primarily for multi-well offshore platforms, multi-well operations on land, deep-water operations, and for situations requiring operators to drill through and place casing across problem formations quickly. This technology was applied successfully to drill through depleted reservoir (problems: wellbore instability, mud losses into the depleted zones).

3.3.1.1 Non-Retrievable System

on-retrievable casing drilling system uses a top drive and casing drive system (CDS) to provide rotation to casing. Singular joints of casing get picked up from pipe rack to be set in mouse hole. The top drive with its added features, is connected to the top joint, locked into casing string top in rotary table and then resume drilling in a conventional way. (K.A. Aleksandrov et al., 2015).

A non-retrievable system can be used to drill with short liners or full casing strings. Conventional drilling bits are replaced with drillable bits that stays in the wellbore after reaching total depth. Drillable bit can be unattached to allow logging operations, or be cemented in place and later drilled through. Figure 15. Both operations are



presented.

Figure 15. Procedure for logging after drilling with casing (Fontenot et al. 2005).

These systems are usually applied in vertical wells in problematic areas that would be faced while using conventional drilling method. Non=retrievable systems can be designed of different tools depending on drilling requirements and conditions. Most common bottom hole assemble contains drillable bit, float collar, stabilizers and high-torque ring on connections.

Drilling Shoe

Casing drill shoe are used for drilling as a normal drilling bit used in conventional drilling, it is designed in a way to make it drillable when the total depth is reached. At the beginning of Casing Drilling operation bit balling, dynamic stability and penetration rate problems usually have been appearing. nowadays there are a lot of companies that provides drillable bits but the company that mostly focusing on this Weatherford. The Weatherford Defyer DPA (Figure 17), is a drillable bit that is designed for formations with medium to hard of hardness. The new design of this bit series includes a selected count of blades and configuration of cutter sizes to fit the formation type and application. It has an aluminum nose, and special steel alloy for blades. Polycrystalline diamond compact (PDC) cutters are placed in an optimal way in the face of the tool in order to maximize drilling efficiency and bit durability (Weatherford, 2014).

Figure 16. Weatherford Drill shoe (Weatherford, 2014).

Float Collar

Float collars (Figure 17) one to three joints above casing drillable they are placed. Float collars provide a cement plugs seat, the bottom plug pumped prior to the cement and the top plug behind the full slurry. Once seated, the top plug shuts off fluid flow and prevents over-displacement of the cement. The area between float collar and bit is a contaminated area to keep the contaminated fluids or likely to be contaminated from the wiper operation of top cement plug, which will secure this contaminated fluid far from shoe in order not to ruin the important part of having a proper cement bond at the shoe. Float collars has an embedded backpressure valve that restricts a back flow of cement to the inner casing string once the cement surpassed the corner to the annulus and top plug is bumped. (Halliburton, 2016).

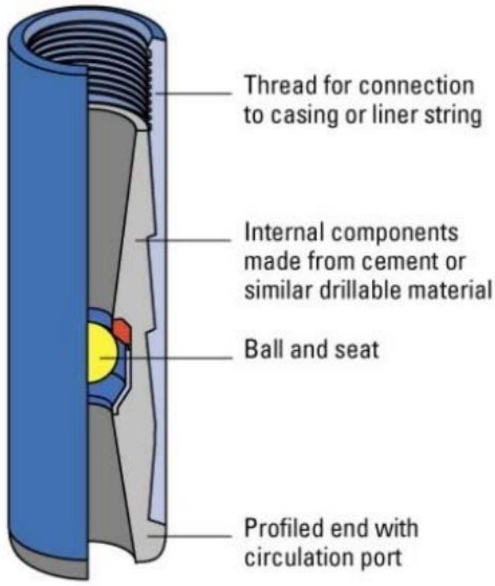


Figure 17. Float collar (Kerunwa and Anyadiegwu, 2015).

3.3.2 Retrievable System

Retrievable casing while drilling BHA system is a balance between conventional drilling equipment and Casing Drilling. The point of this system is that it can be used in directional drilling with the steering ability, and it is used with both conventional measure while drilling (MWD) and logging while drilling (LWD) equipment.

Majority of bottom hole assembly systems are connected to the bottom of the casing string, drilling a pilot hole, which then is enlarged with special methods: a reaming casing shoe, a near casing shoe underreamer, or a near bit underreamer.

The pilot bottom hole assembly is connected with the casing pipes, with Drill Lock Assembly (DLA) used to set in the casing profile nipple (CPN). When total depth (TD) is reached, the bottom hole assembly (BHA) can be retrieved using a drill pipe or a wireline; depending on weight and angle of the bottom hole assembly, the method is determined.

With retrievable BHA system, a rat hole is being created with a length that is identical to the BHA. Thus, some techniques are used to reduce the rat hole length. At first, DLA can be released at the total depth, reamed down with casing reamer shoe down to full bit length, which may lead to some damaging to the bottom hole assembly. Alternative method is to put the underreamer behind bit, once BHA is at bottom or TD, DLA is the released, allowing the casing to be run to the bottom.

However, when placing underreamer behind the bit may affect the use of LWD reading and can impact the performance of directional control. In particularly when rotary steering system (RSS) is being applied with the BHA. RSS is a popular choice when using casing drilling, due to the improved performance rather than mud motors or positive displacement motors (PDMs). (E. Marbun et al., 2012).

Drilling with mud motor is especially difficult to use together with casing drilling, due to the fact that is requires a larger contact area with the wellbore in order to efficiently work and control the tool face. With retrievable system, cementing is usually done after BHA retrieval.

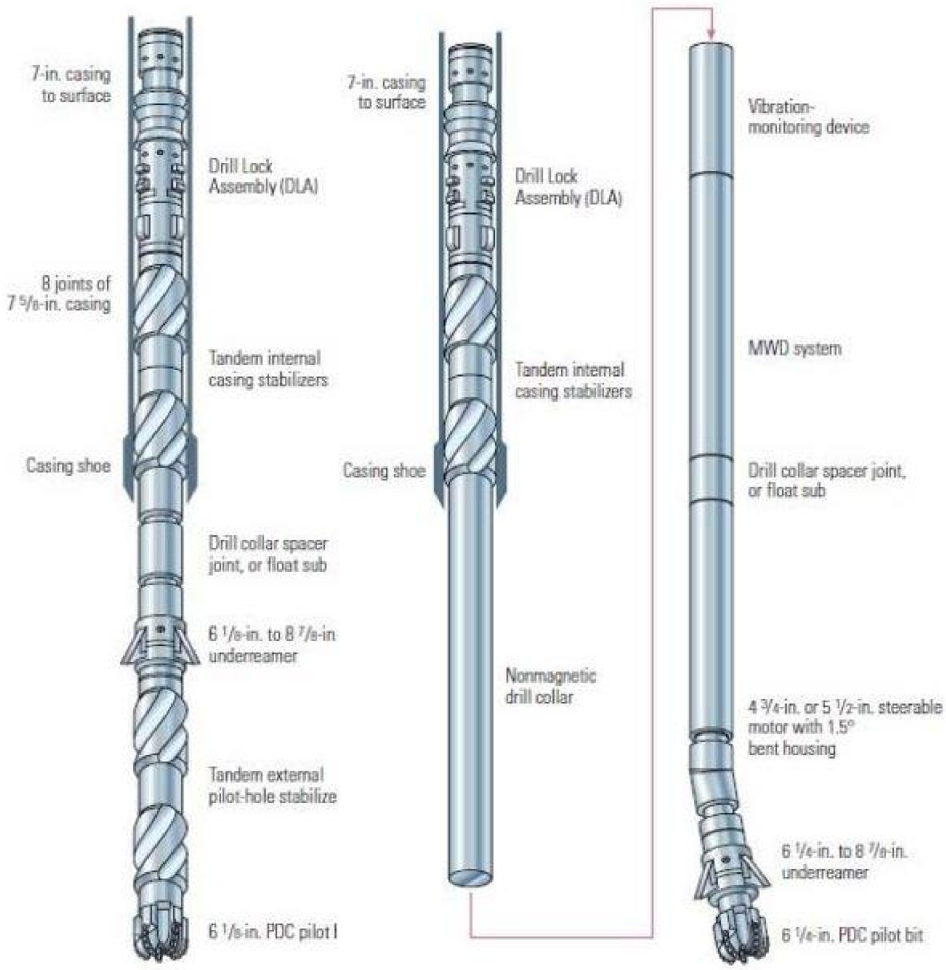


Figure 18. Drilling assembly that is used to drill vertical (left) and directional (right) wells.

Source (modified from Fontenot et al. 2005).

3.3.3 Advantages Of Casing Drilling:

- Get Casing to Bottom

Due to the fact that the wellbore degrades during tripping, the conventional method mostly unable to set casing shoe to the bottom hole. This degrading happens from different factors such as damage in well's wall, mud cake builds up and tripping time which can let some formations to swell and thus, reduce the diameter and cause a premature setting for casing. With Casing Drilling, once TD is reached casing is already also at TD.

- Formation Exposer time is reduced
- Get through troubling zones
- Increased hole cleaning efficiency
- Increased hole quality
- Reducing Mud losses
- Strengthening the well bore
- Improves controlling formation damage
- Reduces risks of operations such as:
    - Pipe sticking
    - Well control

Continued Drilling with Losses

In cases where the drilling mud losses aren't being controlled with mud losses solutions such as mud plugs or cement plugs, or big fractures or caverns, etc. drilling can be resumed with minimized drilling mud losses until the casing reaches the required total depth. There are specific factors that make it possible to continue drilling operation with Casing Drilling. These factors are as following:

- reduced pump rate,
- enhanced well cleaning efficiency,
- Backside pumping ability.

Due to the smaller annulus with Casing Drilling, a lower flow rate for drilling mud is required compared to conventional drilling method to circulate the drilling mud effectively. This lower rate helps to minimize mud losses; especially if the losses are occurring around the drilling bit. The reduced flow rate also controls the ECD to prevent extra pressure faced on the formation which could increase the drilling mud losses. The increased annular velocity helps by increasing well cleaning efficiency, in particular in cases where the partial drilling mud losses column result in breakouts and cavings falling inside the wellbore. With Casing Drilling, it's easier to fill up the back side of the casing thanks to the small annulus. In a drilling with losses situation, this option helps cool off the connections and maintain better well control.

In conventional drilling mothed, when severe drilling mud losses are occurred the drilling process is usually stopped until the losses causes are cured by mud loss control practices such as mud and cement plugs. This will leave several hours of non-productive time (NPT). Casing Drilling allows the operator to continue drilling assuring that once the casing has passed the zone causing mud losses, the trouble is behind, casing down to total depth (TD) and ready to do cement job. Additionally, a major parameter affects the Plastering Effect is the contact time of the casing with the wellbore. With continued drilling, the Plastering Effect starts to fix the zones causing the mud losses or in other wards heal them and this leaves a chance that returns are re-established. This is especially beneficial if the loss zones are in sections above the drilling bit.

3.3.4 Casing Drilling Components

3.3.4.1 Casing Drilling Rig

Casing drilling is carried out using a specially designed drill rig or a conventional rig modified for casing drilling. A top drive drilling rig has a casing drive system (CDS) below it, which allows the casing to connect, rotate and circulate. The rig has an automated hydraulic bridge called a V-door to move each casing joint from the casing strut to the drill floor, whereupon it is lifted by hydraulically activated single joint lifters attached to the CDS, as shown in Fig. 19. The extra time associated with running the drill pipe and running the fixed casing inherent in conventional drilling is successfully eliminated when drilling with casing, since the casing is already set after reaching TD. Thus, NPT and furthermore, less pipe manipulation increases the safety of the wellsite and allows the drillers to use smaller rigs. (IADC Drilling Manual, 2015).

3.3.4.2 Casing Drive System (CDS)

To safely connect individual casings to the string. The pipe handling, connections, rotation moment and fluid transferring will be through the system. CDS is connected to the top drive, and it connects with casing joints using a spear that ball internally and from the outside using slip mechanism, which makes connections and transfer the fluid to the casing. Also, it seals the casing and prevents leaks while drilling fluid is being pumped. The casing is attached to the top drive through the casing drive system without the need of screwing into the top casing connection. The use of CDS and power slips speeds up casing joining connections and reduces the operations required on the rig floor, hence reducing risks.

CDS has two types, internally for bigger casing diameters and external for smaller casing diameter, Figure.19. It has an internal spear assembly that prevent leakages of fluids from the inside of casing out while connecting to the pipe, and a slips assembly for have a grip on the interior of casing with greater diameter of the external for smaller size diameter casing.

A ¼ turn clockwise engages the spear to grip the casing string and the rotating torque is applied. A ¼ turn counter clock without axial load will release the tool. A valve is embedded to prevent any fluid spill when connections are being made. (Warren et al., 2003).

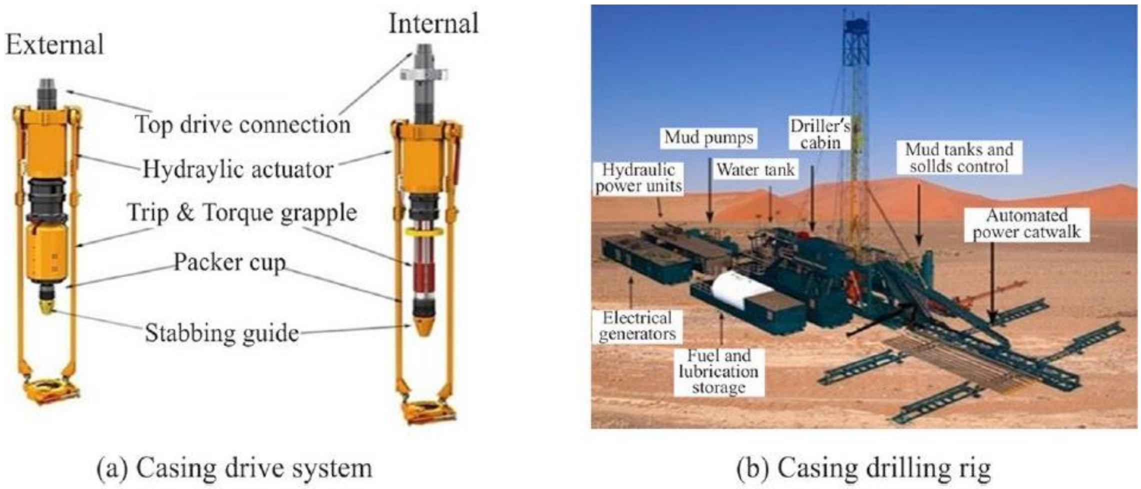


Figure 19**.** Casing Drilling system.

3.3.4.3 Casing String

In casing drilling, the drill string is made up of casing pipes. Casing pipes of the same grade. They act as hydraulic channels for the drilling fluid and transfer mechanical energy to the bit. In addition, a wireline retrievable BHA consists of at least a bit and an expandable reamer that are at the bottom of the casing to drill a well of the appropriate size to allow the casing to pass freely.

In the casing, the BHA is attached to a drill joint (DLA) located above the casing shoe connection and plays a vital role during inserting and removing tools from below. The DLA locks into the casing profile nipple and allows torque and load to be applied to the casing while drilling. DLA has two locking mechanisms types, viz. An axial lock and torsion (figure 20.a). The applied force to the surface secures the axial lock, and when needed it releases the lock, then rotation engages the torsion lock. The DLA component can be a seal between casing string and bottom hole assembly (BHA). That allows the fluid flow through casing through the BHA. The tools are pulled out after a releasing and pulling tool is run on wireline to release the DLA of the casing in a single trip to turn on the DLA, open the bypass and release the axle locks. This twist lick can be unlocked when a reverse torque is applied to casing.

Bottom hole assembly components are specially made in a way to pass through the casing string that has an underreamer (hole enlarger) and a mud motor. Reduced power than the optimum to steer underreamer and drilling bit.

The stabilizer positioned to the opposite of casing drillable bit reduces lateral movement of the assembly inside the casing. The increased torque means that an under gauged hole is being reamed by the reamer. Conventional directional tools can be suspended under casing shoe for directional drilling. (Figure 20.b).

The design aspects of casing when drilling with casing are similar to the design aspects of casing for conventional casing, except with emphasis on buckling, fatigue and hydraulic forces experienced by the casing during the drilling operation.

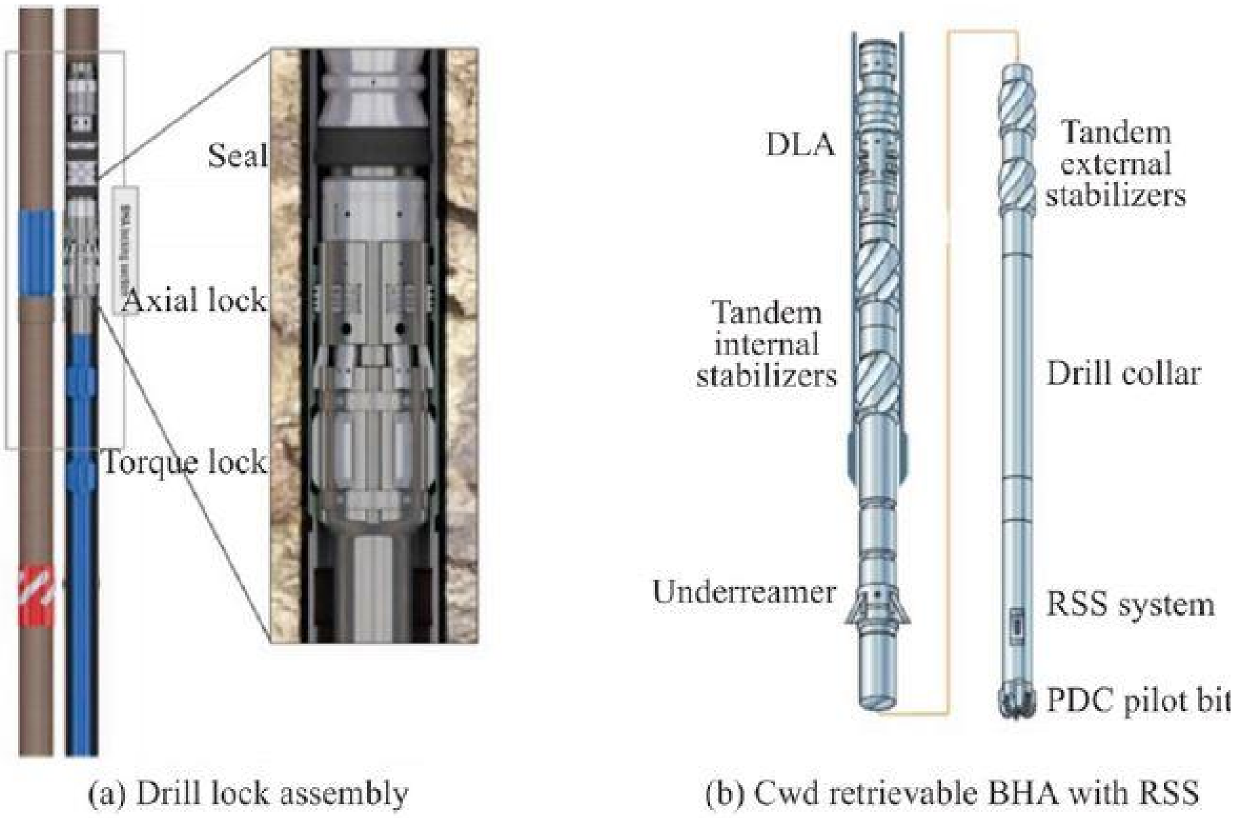


Figure 20. BHA for Casing Drilling system.

3.3.4.4 Casing Drilling Accessories

Major Casing Drilling accessories used for handling the casing and Casing Drilling operations are shown in Fig. 21 and are explained as follows:

- Pump Down Displacement Plug (PDDP)

The plugs are made of natural rubber and the purpose of them is to allow positive placement of cement when its being pumped through casing to the annulus and prevent and any dilution by drilling mud while pumping. Or it is needed to prevent U-pipe effect in cementing while casing drilling. Providing Less chance of mis landing in the well that gives more advantages over conventional float equipment used in conventional drilling.

- Multi-lobe torque ring

The multi-lobe torque ring provides a positive shoulder for increased torque when installed in standard API-Buttress (BTC) threaded connections. This increased torque protects the pins and couplings used in API casing and tubing connections from overstressing while drilling, thereby reducing damage to the tubing connections.

- Wear resistant couplings

Wear resistant couplings are used for the protection of casing from the drilling operation effects They are installed on the wellsite using a portable hydraulic pressure testing tool.

- Centralizers

When drilling with casing pipes, centralizers provide forced centring of the casing string for cementing operations in vertical and directional wells.

- Torque monitoring device

A torque control device located on the floor of the rig is used to monitor

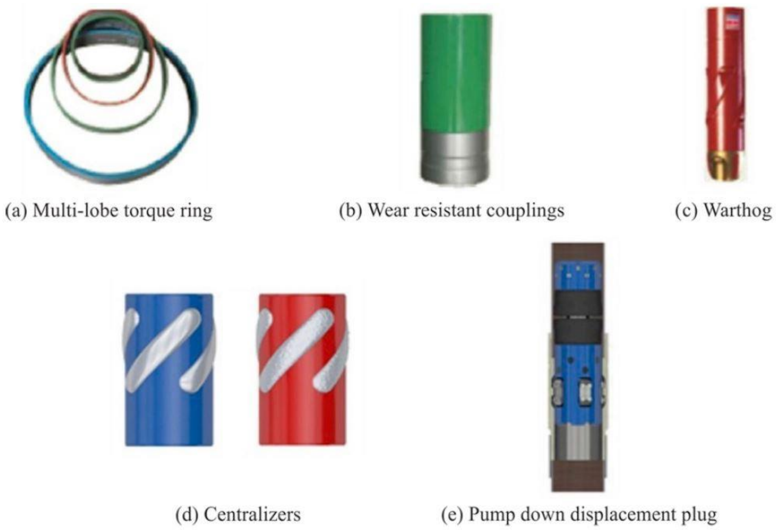


Figure 21. Casing Drilling accessories.

3.3.5 Plastering Effect

During the casing drilling operation, the rotation of the casing and the smaller annulus causes the cuttings to be compressed or smear along the borehole wall, thus strengthening the borehole. This action is called the stucco effect, which restores the hoop stress of the wellbore by jamming formed fractures and / or increasing fracture propagation pressure. This effect seals formation pores to reduce fluid loss and enhances cementing to protect the integrity of a wellbore in a loose formation or drilling into a depleted formation. (V. Naveen et al., 2014)

Centrifugal forces can primarily be responsible for plastering effect. The effect will lead to fewer cutting return to surface while a huge reduction of solid handling problems. Projects what faces a low pressure or weak layers over a potential high-pressure layer while construction using conventional drill pipes are often facing problems with balancing in the weak formations and influxes from the high-pressure formations. Plastering effect can improve the well integrity as well as reducing the circulation losses even when a higher ECD is being faced, thus, it is a considerable effect helping with lowering potential problem which would occur in normal conditions with conventional drilling. (IADC Drilling Manual, 2015). For plastering effect to happen, a ratio of 0.8 (casing diameter to borehole diameter) is being kept. This ration gives the optimum annular pressure and casing diameter for the occurrence of plastering effect.

Figure 22. Plastering Effect.

Source(https://www.slb.com/drilling/bottomhole-assemblies/specialty-drilling-applications).

3.3.6 Well Control for Casing Drilling

The oil and gas industry are getting wider day by day, and oil wells are being drilled in challenging environments using new and innovative drilling technologies. However, each drilling technology needs a special well control design to deal with influxes entering the well while constructing the well. Although there are many reasons for blowouts, the most important are insufficient hydrostatic column, loss of circulation, swabbing, etc. Early detection of blowouts is necessary to prevent uncontrolled well flow. The goal of well control techniques is to remove the inflow from the wellbore by circulating and restoring primary well control. Although the goal of well control remains the same at all times, the well control design changes according to different drilling methods, such as replacing pipe rams with casing rams in a blowout preventer (BOP).

In order to use the well control methods previously mentioned, a modification needs to be applied since a reduced annular clearance and different geometry of the string from conventional methods. During tripping operations, 70% of kick occurs. While casing drilling is applied, these well control problems are avoided since there are no tripping out from bottom hole. The Casing circulation tool CCT is used to seal the annulus internal string casing to prevent influxes from entering the annulus between casing string and previous casing. In case it happens during Bottom hole assembly retrieving, the inner string being applied to a false rotary, and circulating tool with the full opening safety valve (FOSV) is equipped to the lower drill string in casing after closing full opening safety valve (FOSV). (K.S. Graves et al., 2013). The two most widely used methods for controlling a circulating constant bottom hole well are the driller method and the wait and weigh method. The advantages of the driller method are simple calculation and minimum information required, while high annular pressure and longest choke dwell time are disadvantages. The lowest pressure in the wellbore and at the surface, ensuring well control in one circulation and the shortest residence time in the choke are the advantages of the waiting and weighing method, while the longer waiting time before circulation, the complexity of calculations and the immediate need for sufficient weighing materials are some of its flaws. Both methods are applicable to well control while casing drilling, but the wait and weigh method is preferred over the driller method as it allows the well to be killed without damaging of the casing shoe.

Influx and Shallow gas kicks are major challenges in casing drilling due to the lower annulus capacity. The maximum expansion of the gas flow leads to a sudden increase in pressure at the choke surface, which is higher than with conventional drilling. Shallow gas blowout can be prevented by monitoring the ECD. Due to the nonlinear behaviour of the equivalent circulation density, this problem happens more often when drilling directional and horizontal wells Adequate gas seal capability is achieved through the use of a premium metal-to-metal seal shoulder, which is important if there is a high risk of shallow gas outburst. (C. Espinosa et al., 2017).

3.3.7 Challenges In Casing Drilling

Major Challenges associated with Casing Drilling are as follows:

- Increased Torque and drag Because the casing is larger and heavier than drill pipe, the torque required to turn the casing at the bottom is often high.
- Since the annular gap when Casing drilling is very small compared to traditional drilling methods, the hydraulic system needs to be reworked. Because higher ECDs are difficult to control at deeper depths, it is difficult to plan hydraulics for casing at deeper intervals even with optimal mud rheology and reduced flow.
- saving running time is a significant advantage. The casing bit must be designed to complete drilling to the minimum casing depth in one run. Otherwise, the entire casing must be pulled out to replace the bit. Thus, choosing the right bit is a prerequisite for shortening trip times.
- Due to the smaller annular gap, when drilling with casing, gas flow will increase more along the height of the hydrostatic string. Thus, this will cause a sudden decrease in bottomhole pressure, and this situation will cause more hydrocarbons influx from the formation.
- The fatigue failures are more probable to occur in casing with high dogleg that cause high levels of reversal stresses in the casing joints. In order to prevent fatigue failure, a safe speed must be calculated in the preliminary analysis.
- While casing has been shown to reduce daily drilling costs in almost all areas, casing capital costs are still higher. The aforementioned problems need to be addressed in order to get excellent results from casing drilling.

3.4 Hydraulics

3.4.1 Bottom Hole Pressure

There are two different situations concerning down hole pressure which are while the pumps are working, thus the drilling mud is being circulated, in this situation it's a dynamic condition. The other situation is when pumps are not working, a static condition is met, meaning in this situation the drilling fluid is not being circulated, and this leads to some effects taking in place such as settling of cuttings over the time, temperature gradients alongside with formation temperature and mud properties due to temperature and pressure changing.

Such effects being changed will have an impact on downhole condition, thus, bottom hole pressure distribution along the wellbore. Before discussing them, a simplification shall be made in order to make predictions, and they are as following:

- After shutting down the mud pumps Cuttings concentration stays constant.
- An even distribution of cuttings in the well, even under static conditions Fluid properties remain constant.
- Pressure losses from cutting removal out of the well is cancelled.

3.4.1.1 Static Conditions

In static condition the bottom hole by height and density of the fluid column or hydrostatic pressure as following:

$$P_{hs} = \rho g h$$

Where ρ : fluid density, g gravitational constant and h vertical depth.

A successful solid transporting to the surface is must be made to avoid drilling problems. Drilling fluid contains a certain quantity of solids at any time, thus, quantified by a parameter

$$c_{p,0} = \frac{solid\ volume}{mud\ vol. + solid\ vol.}$$

When a well is in a static condition for a period of time will in practice have $c_{p,0} = 0$, as the solids have in the fluid may have settled depending on mud rheology and wellbore geometry and cuttings density. Combined Drilling mud density and solids

$$\rho_{mix} = \rho_{mud} * (1 - c_{p,0}) + c_{solids} * c_{p,0}$$

substituting ρ_{mix},

$$P_{hs} = (\rho_{mud} * (1 - c_{p,0}) + c_{solids} * c_{p,0}) * g * h$$

3.4.1.2 Dynamic Conditions

The total Annular Friction Pressure Loss depends on different parameters, such as wellbore geometry, fluid flow regime and parameters, drill pipe rotation and drill string dynamics.

Hydraulic friction should be estimated as accurately as possible in order to (Thingbø, 2011):

- Optimizing Rate of penetration (ROP) by using the optimal bit nozzle size.
- Improve cutting transporting efficiency.
- Optimal pump size selection.
- Approximating annular pressure losses to stay in drilling mud window.
- Detect any unexpected changes in SPP due to change in the hydraulic circuit

Cutting concentration in dynamic systems ratio $c_{p,0}$ should be expressed in flow rates terms.

$$c_{p,0} = \frac{q_{solids}}{q_{mud} + q_{solids}}$$

Volume rate of solids trapped in the drilling mud:

$$q_{solids} = ROP * \left(\frac{d_{bit}}{2}\right)^2 * \pi$$

The equivalent circulation density (ECD) is the sum of hydrostatic pressure and pressure loss due to fiction.

$$ECD = P_{hs} + \Delta p_f = \rho_{mix} g h + \Delta p_f$$

Where P_{hs} is hydrostatic pressure and Δp_f is difference in pressure due to friction or called the annular pressure loss.

3.4.2 Flow Regimes

All fluid flows are classified into two broad categories. These two regimes are Laminar flow and turbulent flow. The Laminar flow is a smooth streamline and an ordered flow or moving in parallel layers, and usual encountered with highly viscous fluids in small pipes.

Figure 23. Laminar Flow

Wall roughness affect the transition regime between Laminar and Turbulent and inlet and outlet effects, yet the most significant factor is the Reynolds number When the

Reynolds Number exceeds a certain threshold, the streamlines characterizing laminar flows start the be more chaotic, and the regime starts to switch to turbulent flow regime. Turbulent flow regime is when local velocity fluctuates and chaotic motion. From Laminar to Turbulent Flow is period which happens step by step, it is called a transient, until it become a fully developed turbulent flow.

$$N_{RE}\frac{\rho v D}{\mu}$$

Where:

$\rho = fluid\ density\left[\frac{kg}{m^3}\right],\ v = average\ fluid\ velocity\left[\frac{m}{s}\right], D = diameter\ of\ pipe\ [m],$

$$\mu = dynamic\ viscosity\ [Pa * s]$$

Laminar flow is usually when Reynolds number is $N_{RE} < 1800$ and a fully developed turbulent flow is when $N_{RE} > 2100$. The in between interval $1800 > N_{RE} > 2100$ is the transitional flow which parts may be a laminar and other parts are turbulent.

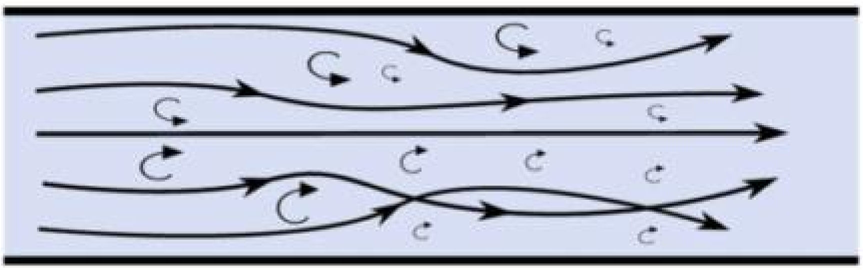


Figure 24. Turbulent Flow

There is an importance of understanding the pressure drop due to the annular friction concept and annular moving velocity due to the low clearance between the wellbore and casing pipes unlike the conventional drilling pipes where there is more space between pipes and wellbore. In order to discuss these topics, drilling fluid hydraulics will be discussed in this part. In addition to drilling mud properties, fluid models and frictional pressure loss calculation are discussed.

3.4.3 Rheology of Drilling Mud

Rheology is the science that studies the deformation and flow of matter. Fluids are subcategorized into the rheological models based on the relation between its shear stress and shear rate curves. Where shear stress is the equivalent force to keep a particular type of flow. Shear rate is ratio of relative velocity of moving surface to adjacent surface over distance between them. The fluid response on the shear stress versus shear rate curve indicates the type of fluid, Newtonian fluid and non-Newtonian fluid. Rheological properties such as viscosity, yield point and gel strength and rheological model.

Usually, the fluids of interest in drilling world showed sensitivity to shear rate instead of time, thus, to describe the fluids in a better way, several fluid models have been suggested which are bingham plastic model, power low model and yield power law model.

Shear stress and shear rate are calculated using data from Fann VG viscometer and the corresponding values are expressed in secondary axis.

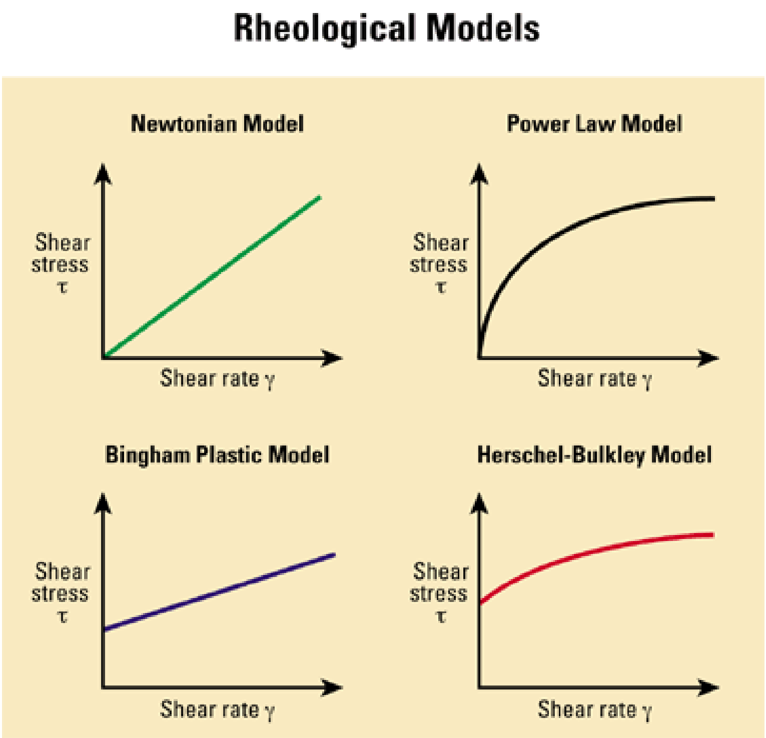


Figure 25. Rheological Models

Source: glossary.oilfield.slb.com

Bingham plastic model.

It is a rheological model the has two parameters, widely used in the drilling mud industry to explain the characteristics of the various drilling mud types used. It can be described mathematically as follows:

$$\tau = \mathrm{YP} + \mathrm{PV}(\gamma)$$

where (τ) shear stress, (γ)shear rate, (YP) yield point and (PV) plastic viscosity.

Fluids which follow this model, called Bingham plastic fluids, exhibit linear shear-stress, shear rate behaviour after reaching the initial threshold shear stress. Plastic viscosity (PV) is the slope of the line and yield point (YP) is the threshold stress. PV should be as low as possible for fast drilling and best by minimizing colloidal solids. YP must be high enough to carry cutting from drilling up to the surface but not over pressurize the pump when starting the drilling fluid. YP is governed by a reasonable choice of mud treatments. The direct indicating rotary rheometer has been specially designed for the application of Bingham's plastic fluid model.

By using readings from Fann VG viscometer, we can calculate Plastic viscosity and yield point.

$$\mu_p = \theta_{600} + \theta_{300}$$

$$\tau_y\left(\frac{lb}{100ft^2}\right) = \theta_{300} - \mu_p$$

And y effective viscosity of the fluid is given by

$$\mu_e = \mu_{p+}\frac{\tau_y}{\gamma}$$

Power law model

The parabolic trend in the shear stress – shear rate plot is Power law model. Like the curve trend for the Newtonian fluids, curve starts from origin and based on (n) which is power law index, it shows a parabolic curve. When n>1 power flow fluid is considered as shear thickening, and when n>1 its shear thinning fluid. The power law index (n) and consistency index (K) and also the apparent viscosity of the power law fluid is as following: (Bourgoyne et al. 1986).

$$n = 3.32log\left(\frac{\theta_{300}}{\theta_{300}}\right)$$

$$k = \left(\frac{511\theta_{300}}{511^n}\right)$$

$$\mu = K(\gamma)^{n-1}$$

Yield power law model

As known as Herschel-Bulkley model and nearest to the typical drilling fluid. This model is a summary of the combination of bingham plastic fluid and power law fluid. Similar to the bingham plastic fluid behaviour the yield stress should flow, and shear stress to shear rate trend curve is parabolic same to the power law fluid behaviour. Shear stress (τ) and effective viscosity (μ) of the yield power law fluid is given as: $\tau = \tau_y + K(\gamma)^n$

$$\mu = \frac{\tau_y + K(\gamma)^n}{\gamma}$$

3.4.4 Fluid Flow and Annulus Frictional Pressure Loss

The behaviour of fluid flow (pressure and velocity) is generated by the theology of the fluid, geometry of the well and flow rate. In Casing Drilling the clearance is low meaning a significant change in velocity profile. The behaviour of fluid flow (pressure and velocity) is generated by the theology of the fluid, geometry of the well and flow rate. In Casing Drilling the clearance is low meaning a significant change in velocity profile. The International Well Control Forum (IWCF) explained the bottom hole flowing pressure as the total of static bottomhole pressure and the annular pressure loss. (IWCF, 2006). As the flowing bottomhole expressions in the terms are changed to equivalent mud weight from pressure, the ECD is going to be as following:

$$ECD = \frac{\Delta P_{friction} + P_h}{D}$$

Where P_h is mud hydrostatic pressure in annulus, $\Delta P_{friction}$is the total of annulus pressure losses due to friction and D is depth. The annular pressure losses become a value that has an impact, due to the fact that ECD can occasionally be greater than formation fracture gradient. Generally, when drilling fluid weight is held constant, ECD is exposed to limited change, and frictional pressure decrease does not play a huge role in hydraulics design for conventional drilling geometries. Nevertheless, the application of this approach to the Casing Drilling circumstances becomes hazardous. In Casing Drilling technology, the annular pressure losses prevail. Slimhole Drilling applications show a similarity with Casing Drilling in this area with the tight annulus clearance and annular pressure losses. In a way of controlling dynamic bottom hole pressure (regarding ECD) is by controlling the mud weight. As the mud weight lowers, the hydrostatic pressure of the mud column in the annulus lowers. The rheological property of drilling mud is another parameter to change in order to reduce ECD, for example, reducing plastic viscosity is a way to reduce ECD. Last action that can affect the ECD is the flow rate, based on that, reducing velocity in annular space and lowering frictional pressure losses. Rather than individual application of any of the three methods, they should be changed and optimized to reach the best results possible. This has a significant impact on wellbore cleaning quality. (Karimi et al., 2012).

Narrow Slot Approximation Method for Annular Frictional Pressure Loss Using

An estimation for annular flow can be made using the equations for flow through the rectangular space. The slot flow equations are easier to use and are reasonably accurate as long as $r_1/r_2 >$ is greater than 0.3. Figure 26 shows an annular space that can be illustrated as a narrow slot having an area (Bourgoyne et al. 1986).

$$A = Wh = \pi(r_2^2 - r_1^2)$$

the flow rate in terms of the mean flow velocity v and solving for the frictional pressure gradient gives $\frac{d_p}{d_l}$

$$\frac{d_p}{d_l} = \frac{12\mu v}{(r_2^2 - r_1^2)^2}$$

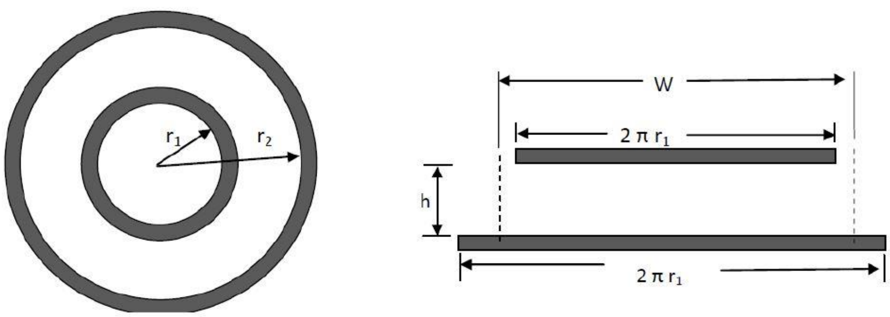


Figure 26. Representing the annulus as a slot: (a) annular and (b) equivalent slot

Determination of shear rate

In order have an increased accuracy in the pressure loss approximation, a deeper knowledge required of shear rate present in the well. Precautions can be considered to measure the apparent fluid viscosity at values of shear rates close to the present in the well. When case is over, improved accuracy may be archived while using the flow equations for Newtonian fluids even when the fluid does not flow near the Newtonian model over a wide range of shear rates. Maximum value of shear rate happens at the walls of the pipe. Thus, shear stress at the wall where r= rw is given by,

$$\tau_w = \frac{r_w}{2}\frac{dp}{dl}(For\ \ circular\ pipe)$$

The shear stress for an annulus (slot flow approximation) is given by

$$\tau_w = \frac{h}{2}\frac{dp}{dl} = \frac{(r_2^2 - r_1^2)}{w}\frac{dp}{dl}$$

In table 7. Is a compilation of equations of velocity and pressure loss equations are summed which can be useful for calculation pressure for both laminar and turbulent flow of fluids under normal circumstances.

Table 7. Compilation of velocity and pressure loss calculation equations.

		Bingham Plastic	Power Law
Mean Velocity	Pipe	$v = \frac{q}{2.448d^2}$	$v = \frac{q}{2.448d^2}$
	Annulus	$v = \frac{q}{2.448(d_2 - d_1)^2}$	$v = \frac{q}{2.448(d_2 - d_1)^2}$
Frictional Pressure Loss – laminar flow	Pipe	$\frac{dp}{dl} = \frac{\mu pv}{1500d^2} + \frac{\tau_w}{225d}$	$\frac{dp}{dl} = \frac{Kv^n(\frac{3+\frac{1}{n}}{0.208})^n}{144000d^{(1+n)}}$
	Annulus	$\frac{dp}{dl} = \frac{\mu pv}{1000(d_2 - d_1)^2} + \frac{\tau_w}{200(d_2 - d_1)}$	$\frac{dp}{dl} = \frac{Kv^2(\frac{2+\frac{1}{n}}{0.208})^2}{144000(d_2 - d_1)^{(1+n)}}$
Frictional Pressure Loss – Turbulent flow	Pipe	$\frac{dp}{dl} = \frac{\rho f_d v^2}{25.8d}$	$\frac{dp}{dl} = \frac{\rho f_f v^2}{25.8d}$
	Annulus	$\frac{dp}{dl} = \frac{\rho f_f v^2}{25.8(d_2 - d_1)}$	$\frac{dp}{dl} = \frac{\rho f_f v^2}{25.8(d_2 - d_1)}$

Chapter 4 Proposed Plan and Required Calculations

Based on the time distribution part, it can be concluded that the problematic zones in the 17 ½" and 12 1/4 "consumed the majority of time to overcome with a 69%. The productive, non-productive and lost time are distributed as following:

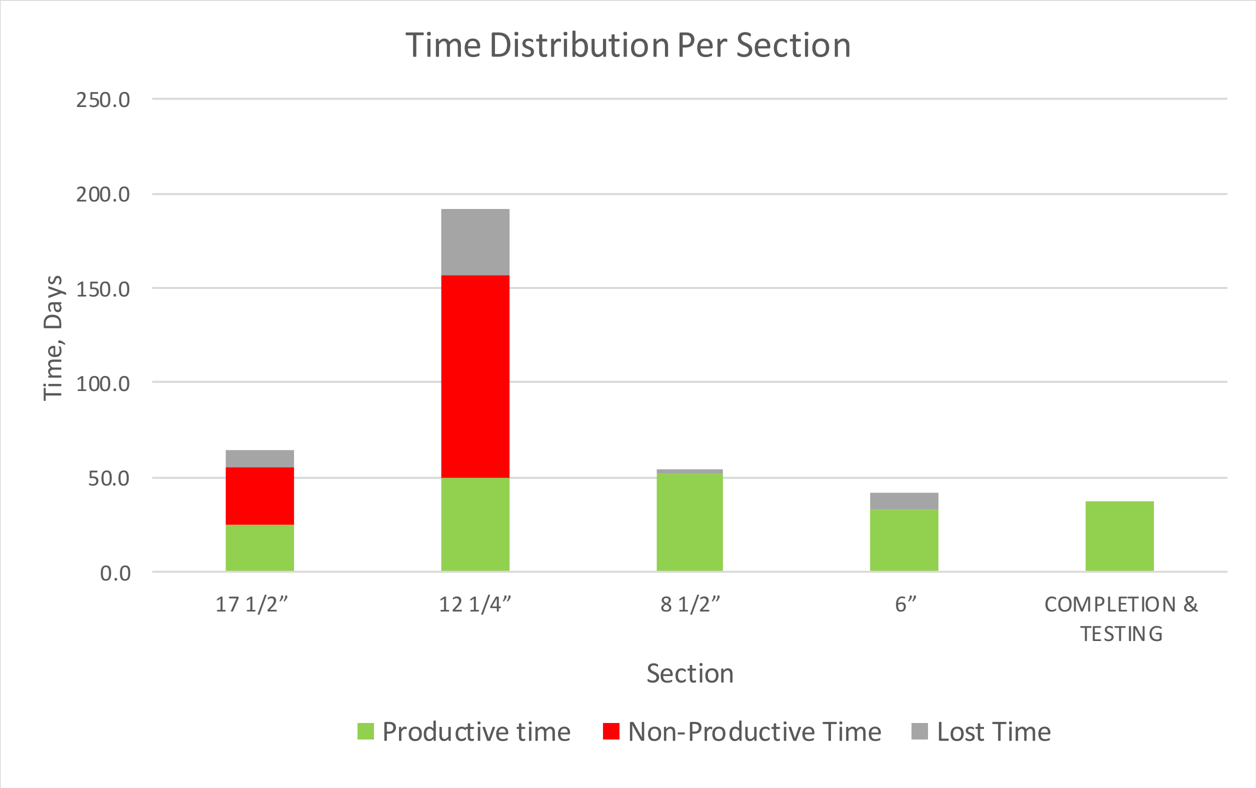


Figure 27. Categorized Time Distribution

Thus, the Managed Pressure Casing Drilling was the proposed solution after analysing the problems face and taking inconsideration the procedures that was taken as a way to overcome those problems.

Managed pressure drilling technology with Mud cap Drilling mode being installed and used to help maintaining the control over the well during problems faced with the fluid losses and in particularly severe losses, by helping overcoming the pressure differences and dealing with kicks if encountered.

When the first fractured is encountered, mud cap is implemented right away. For securing the well from kicking in case pumps were shut off or a sever mud losses encountered and no mud left in the annulus. A heavy kill mud is pumped in the annulus, usually used 15-18 ppg mud. No returns to the surface will be happening if mud weight is correct, otherwise it needs to be recalculated and pumping the new kill mud. Sacrificial fluid is pumped then in order to continue drilling. At this point, drilling mud with cuttings are going into the fractures in the formation.

4.1 Well Program with MPCD

1. Non-retrievable system for both sections. The 17 ½″ section from surface to 500 with 13 3/8″ casing pipes. To the depth as was planned in conventional method plan. With a 17 ½″ drillable casing she as a drill bit type XCD419PDC as showing in the figure:

Figure 28. 17 ½″ drillable casing bit type XCD419PDC

This drillable casing bit can drill up to 700 meters and has a 25 m/h rate of penetration (ROP).

2. The 12 ¼″ section from 500-1320m. Using 9 5/8″ Casing pipes with a 12 ¼″ drillable casing bit type XCD716PDC. This drillable casing bit type has successfully drilled 800m with an 18 m/h rate of penetration in the middle east.

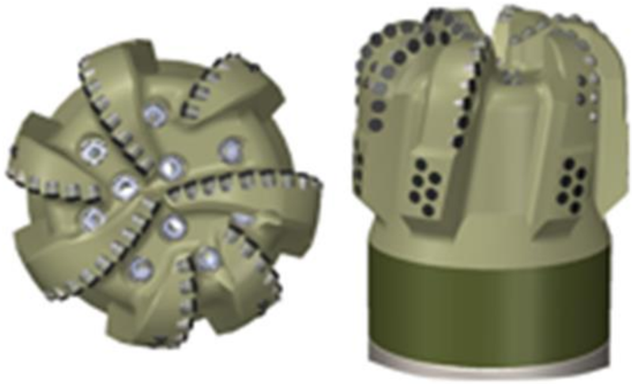


Figure 29. 12 ¼" drillable casing bit type XCD716PDC.

4.2 Required Calculations

All calculations were done using Wellplan, Haliburton Program.

The calculations showed no problems related to toque and drag, rig limitation and

4.2.1 General Input Data

Table 8. Pore Pressure

True Vertical Depth (TVD) (m)	Pore Pressure (psi)	Equivalent Mud Weight (EMW) (ppg)
0.00	0.00	0.80
500.00	282.92	3.32
1000.00	852.17	5.00
1500.00	1591.42	6.22
2000.00	2317.89	6.80

Table 9. Fracture Gradient

True Vertical Depth (TVD) (m)	Fracture Pressure (psi)	Equivalent Mud Weight (EMW) (ppg)
0.00	0.00	9.13
100.00	155.61	9.13
200.00	314.62	9.23
300.00	475.51	9.30
400.00	668.10	9.80
500.00	869.21	10.20
1000.00	2028.16	11.90
1500.00	3323.45	13.00
2000.00	4533.52	13.30

4.2.2 17 ½″ Section

4.2.2.1 General Information

In this section a 17 ½″ Drillable Bit is used and 13 3/8″ Casing pipes with a grade of J-55.

The input and output values are shown in the following tables.

Table 10. Hole Section

Section Type	Section Depth (m)	Section Length (m)	Shoe Depth (m)	ID (in)	Drift (in)	Eff. Hole Diameter (in)	Coefficient of Friction	Linear Capacity (bbl/ft)	Volume Excess (%)
Open Hole	500.00	500.000		17.500		17.500	0.30	0.2975	0.00

Table 11 String Details

Type	Length (m)	Depth (m)	Body		Stabilizer / Tool Joint				Weight (ppf)	Material	Grade	Class
			OD (in)	ID (in)	Avg Joint Length (m)	Length (m)	OD (in)	ID (in)				
Casing	500	500	13.375	12.415	12.19		14.375		68	CS_API 5CT	J-55	
Bit	0	500	17.5		0.3				565			

Table 12. Grade in Use

Grade	Minimum Yield Stress (psi)
J-55	55,000

4.2.2.2 Schematics

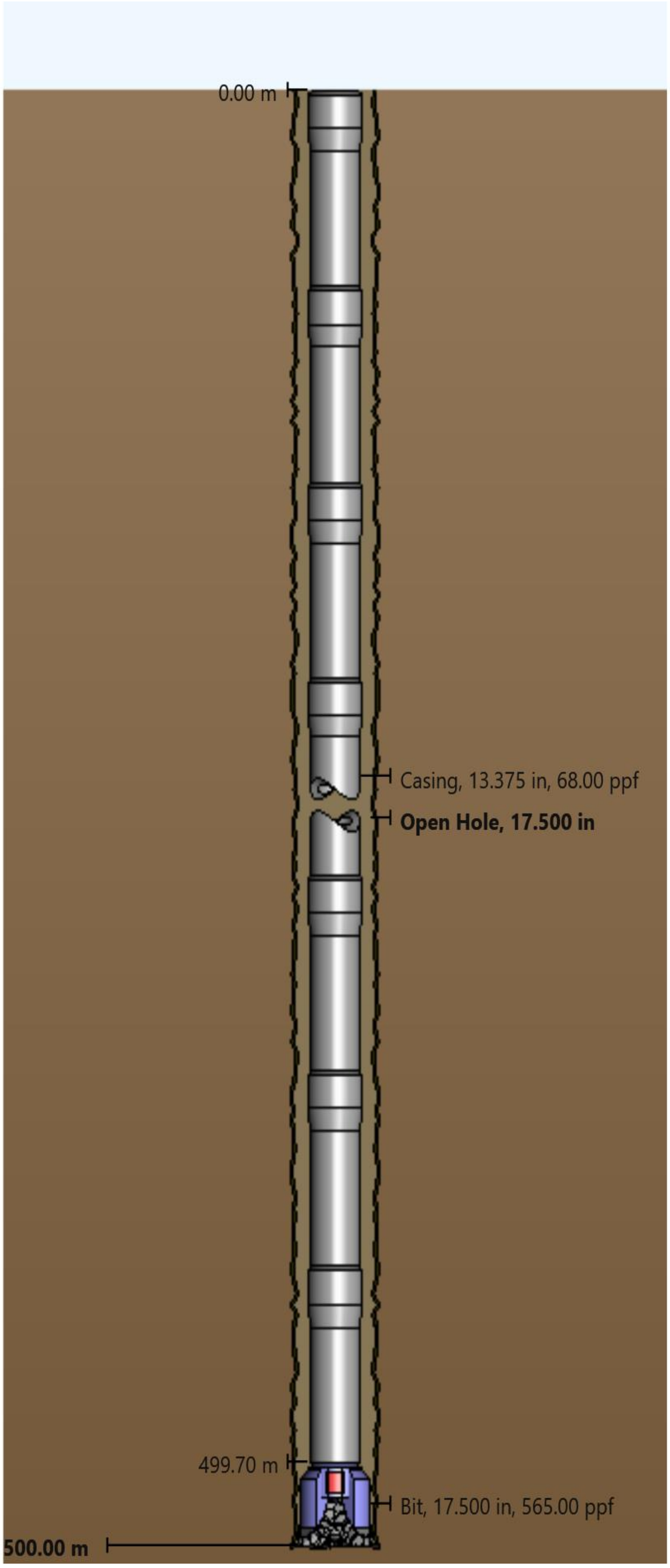


Figure 30. 17 1/2" Schematics

4.2.2.3 Torque and Drag

From the torque and drag outputs, there was no problems related to effective tension, hook load, or rotating on bottom stress.

The following tables shows the input and output values:

Table 13. Mechanical Limitations

Overpull Margin during a Tripping Out operation	859.4 kip	using	90.00% of yield
Minimum Weight on Bit to Sinusoidal Buckle during a rotating on bottom operation	12.4 kip	at	500.00 m
Minimum Weight on Bit to Helical Buckle during a rotating on bottom operation	17.8 kip	at	500.00 m
Pick-Up Drag	0.0 kip		
Slack-Off Drag	0.0 kip		
Block Rating (Hoisting System)	750.0 kip		
Torque Rating (Rotating Equipment)	ft-lbf		

Table 14. Load Summary

Load Condition	Stress Failure			Buckling Limits				Torque at the Rotary Table (ft-lbf)	Total Windup with Bit Torque (revs)	Total Windup without Bit Torque (revs)	Measured Weight (kip)	Total Stretch (m)	Axial Stress = 0		Neutral Point Distance from surface (m)	Neutral Point Distance from Bit (m)
	Fatigue	90% Yield	100% Yield	Sinusoidal	Helical	Lockup	Torque Failure						Distance from Surface (m)	Distance from Bit (m)		
Rotating On Bottom								100000.0	0.0	0.0	130.7	0.04	500.00	0.00	436.80	63.20

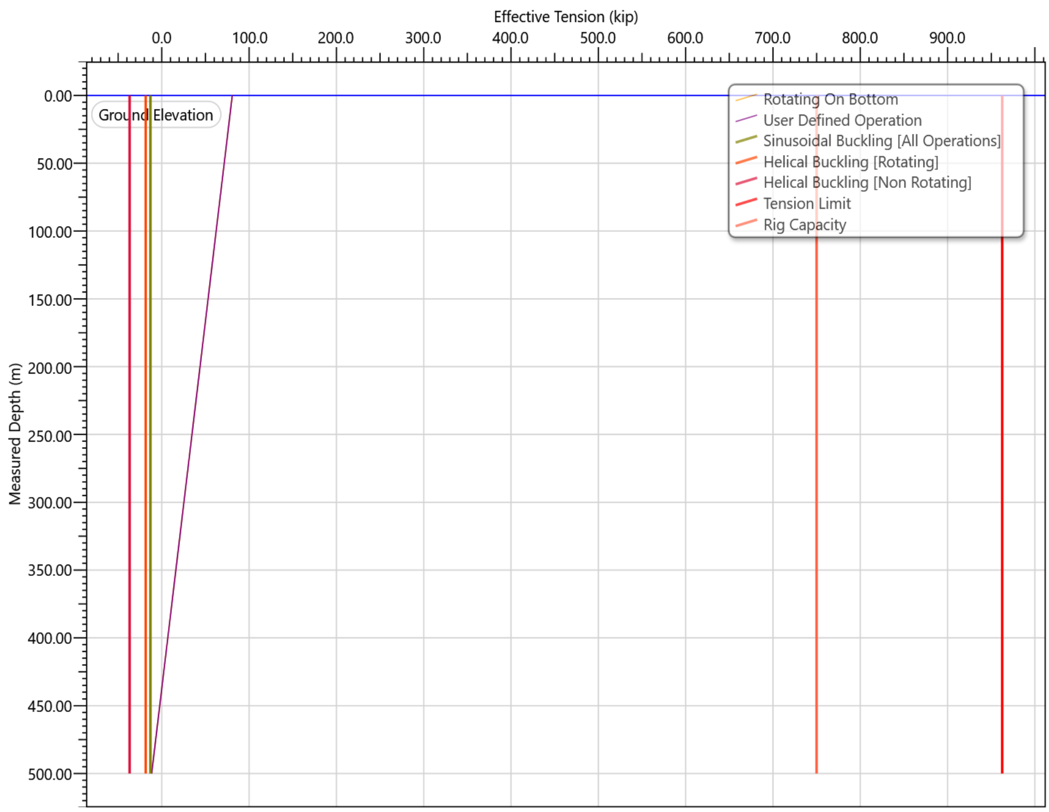


Figure 31. Effective Tension

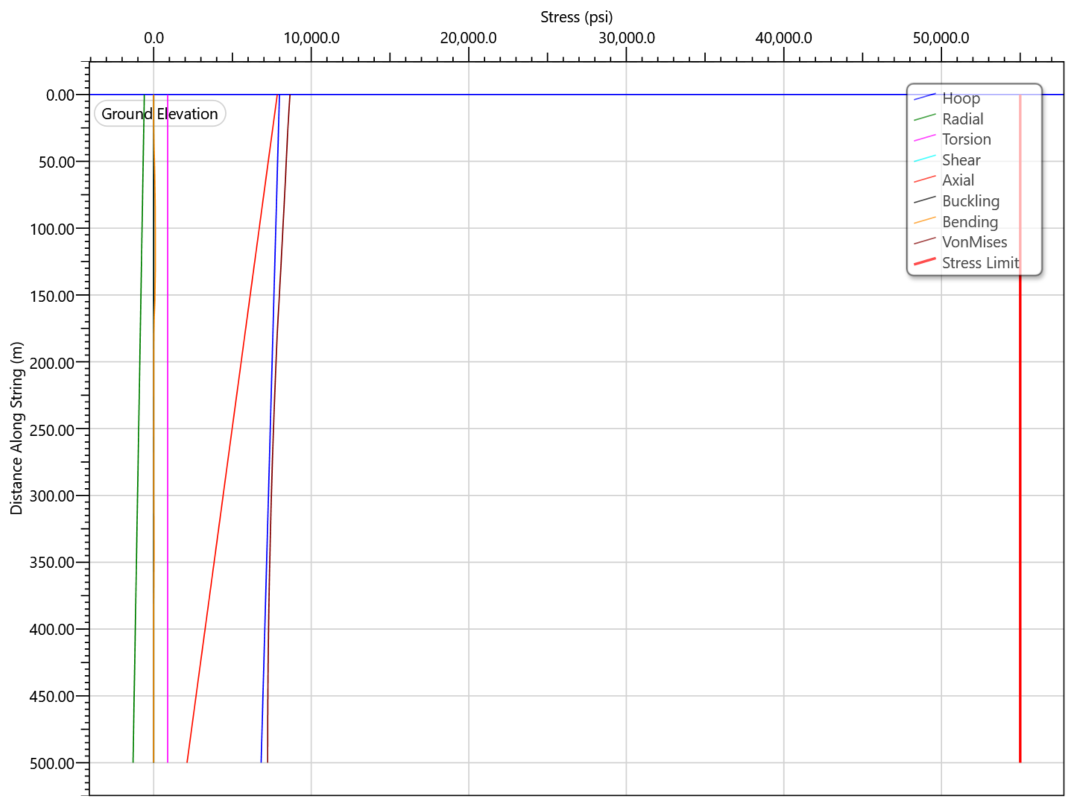


Figure 32. Stresses on bottom

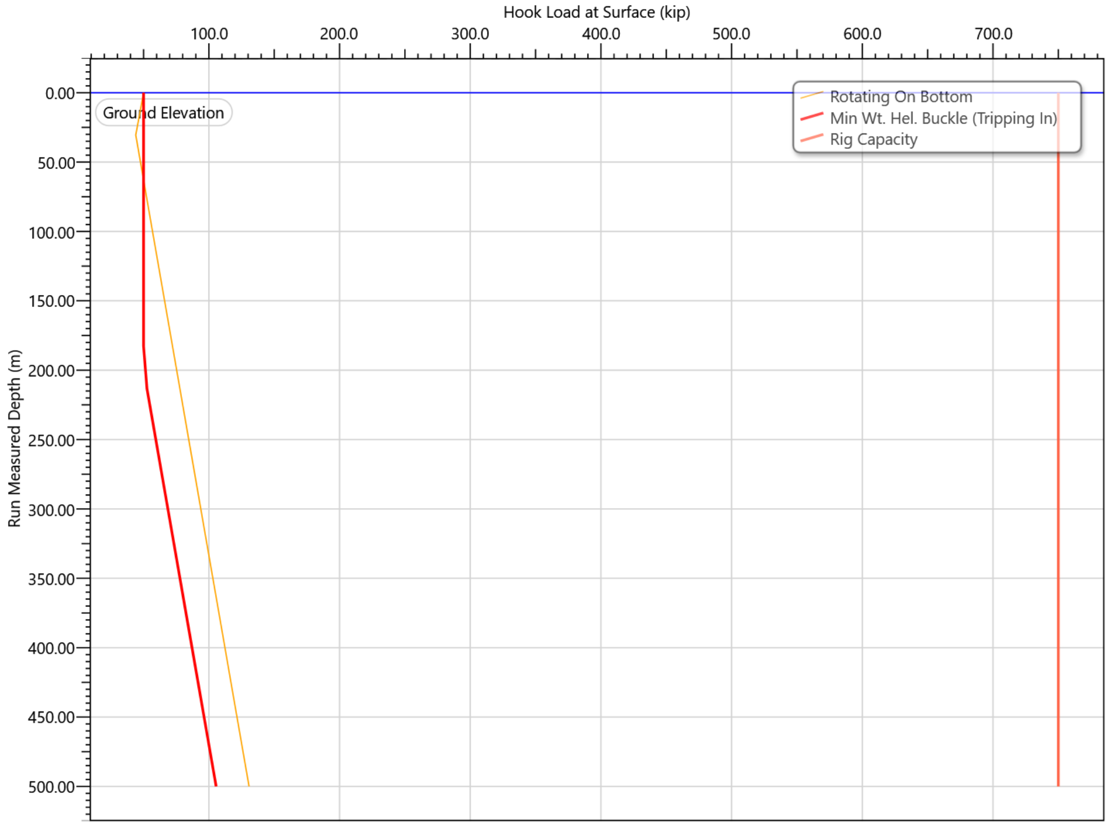


Figure 33. Hook Load

4.2.2.4 Hydraulics

Concerning circulation pressures and ECD, the outputs showed no problems are expected. The pump rate was used the same as in conventional drilling method.

Table 15. Pump Pressure Information

Pump Rate	500.0 gpm
Maximum Allowable Pump Rate	1321.9 gpm

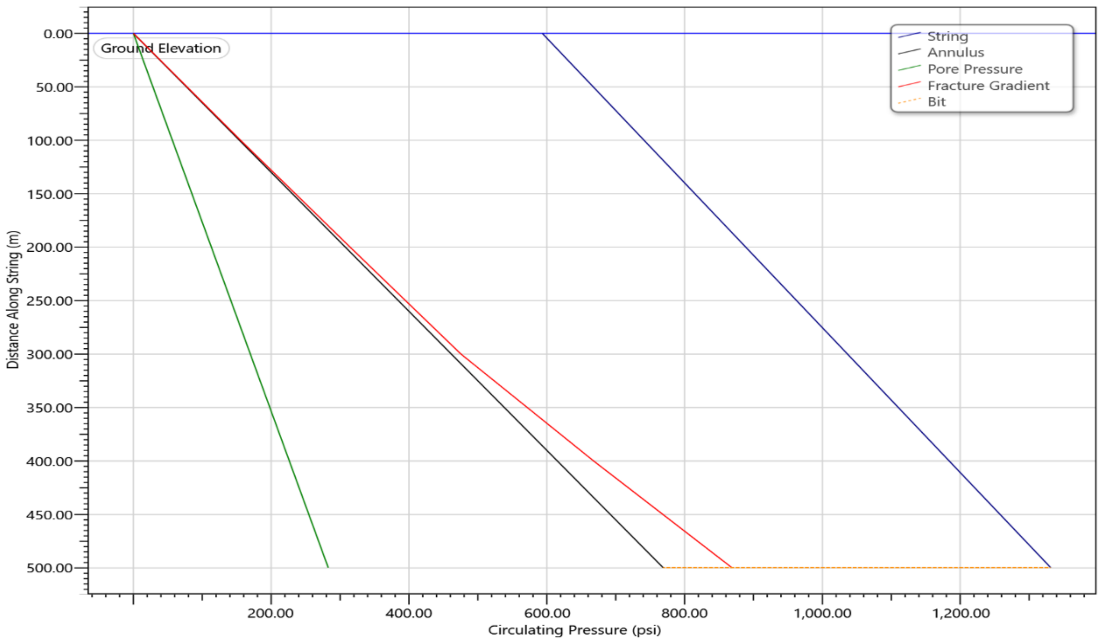


Figure 34. Circulating Pressure vs. Depth

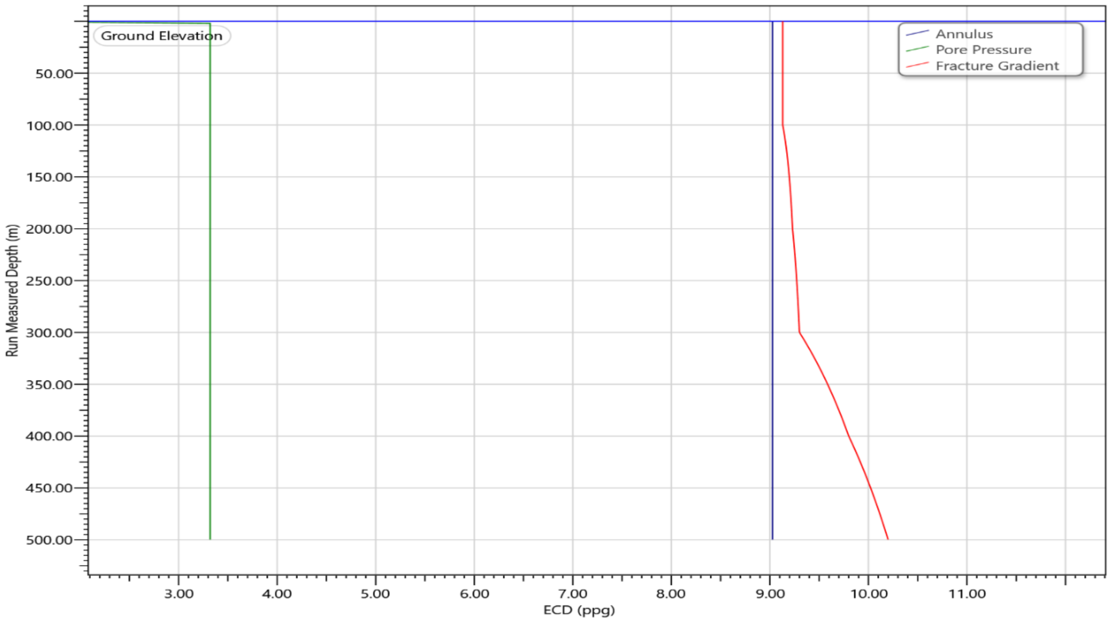


Figure 35. ECD vs. Run Depth

4.2.3 12 ¼″ Section

4.2.3.1 General Information

In this section a 12 ½″ Drillable bit is used and a 9 5/8″ casing pipe with a N-80 grade. The outputs showed no problems are expected to be encountered.

The used parameters are as following:

Table 16. Hole Section

Section Type	Section Depth (m)	Section Length (m)	Shoe Depth (m)	ID (in)	Drift (in)	Eff. Hole Diameter (in)	Coefficient of Friction	Linear Capacity (bbl/ft)	Volume Excess (%)
Open Hole	1320.00	820.000		12.250		12.250	0.30	0.1458	0.00
Casing	500.00	500.000	500.00	12.615	12.459	17.500	0.25	0.1546	

Table 17. String Details

Type	Length (m)	Depth (m)	Body		Stabilizer / Tool Joint				Weight (ppf)	Material	Grade	Class
			OD (in)	ID (in)	Avg Joint Length (m)	Length (m)	OD (in)	ID (in)				
Casing	1,320	1,320	9.625	8.681	12.19		10.625		47	CS_API 5CT	N-80	
Bit	0	1,320	12.25		0.3				267			

Table 18. Grade in use

Grade	Minimum Yield Stress (psi)
N-80	80,000

4.2.3.2 Schematics

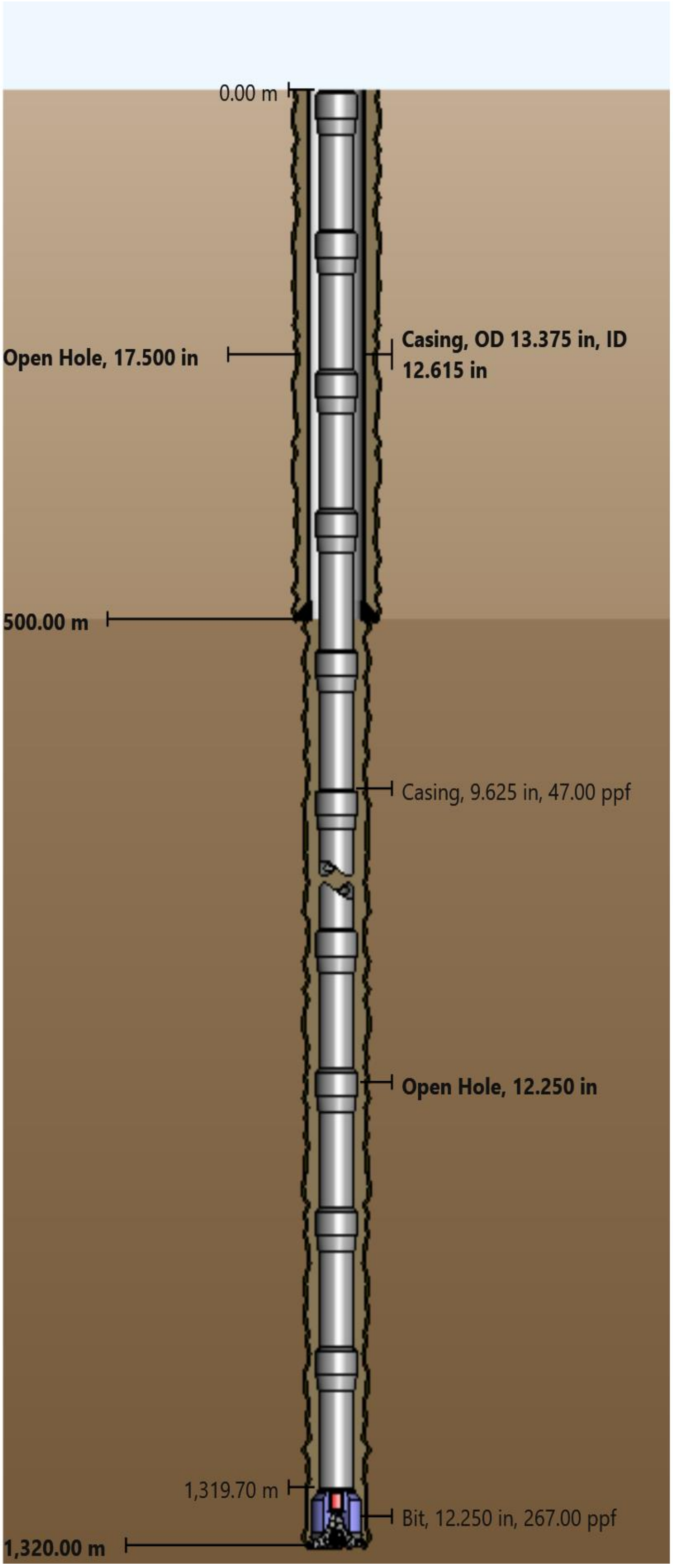


Figure 36. 12 1/4" Schematics

4.2.3.3 Torque and Drag

No problems are expected to be encountered regarding torque and drag while drilling this section.

The following tables shows the input and output values were used in calculations:

Table 19. Mechanical Limitations

Overpull Margin during a Tripping Out operation	809.1 kip	using	90.00% of yield
Minimum Weight on Bit to Sinusoidal Buckle during a rotating on bottom operation	6.8 kip	at	1320.00 m
Minimum Weight on Bit to Helical Buckle during a rotating on bottom operation	9.8 kip	at	1320.00 m
Pick-Up Drag	0.0 kip		
Slack-Off Drag	0.0 kip		
Block Rating (Hoisting System)	750.0 kip		
Torque Rating (Rotating Equipment)	ft-lbf		

Table 20. Load Summary

Load Condition	Buckling Limits				Torque at the Rotary Table	Total Windup with Bit Torque	Total Windup without Bit Torque	Measured Weight	Total Stretch	Axial Stress = 0		Neutral Point Distance from surface	Neutral Point Distance from Bit
	Sinusoidal	Helical	Lockup	Torque Failure	(ft-lbf)	(revs)	(revs)	(kip)	(m)	Distance from Surface (m)	Distance from Bit (m)	(m)	(m)
Rotating On Bottom	X	X			100002	0.3	0.0	204.5	0.24	1196.06	123.94	1228.76	91.24

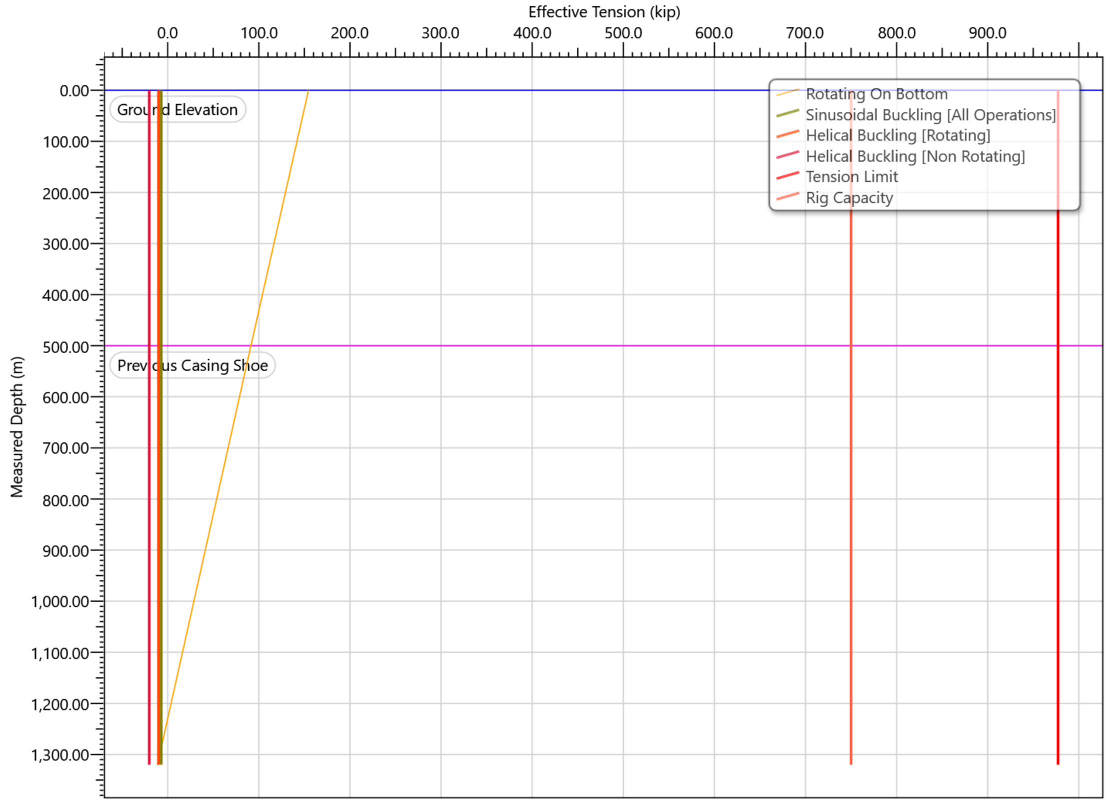


Figure 37. Effective Tension

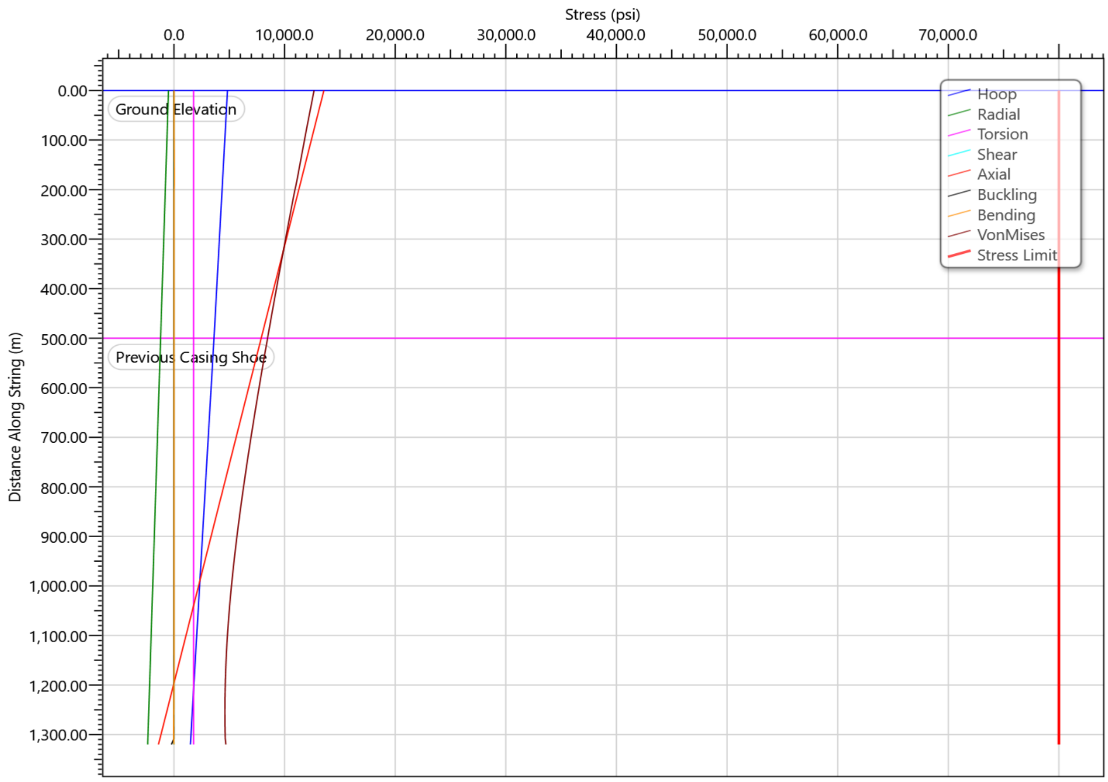


Figure 38. Stress: Rotation on bottom

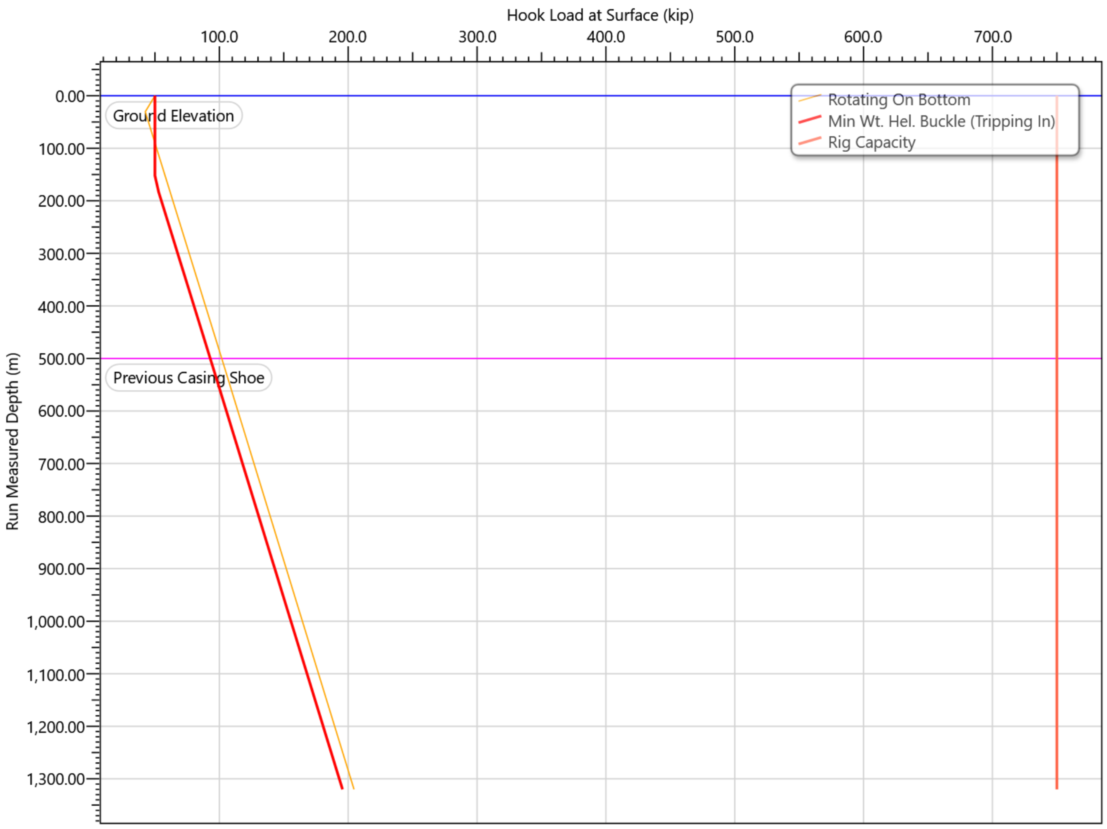


Figure 39. Hook Load

4.2.3.4 Hydraulics

Same drilling fluid and pump rate was used to drill this section as in conventional method that was used. The output of the calculations showed no problems are expected to encountered during operations.

Table 21. Pump Pressure Information

Pump Rate	400.0 gpm
Maximum Allowable Pump Rate	1321.9 gpm

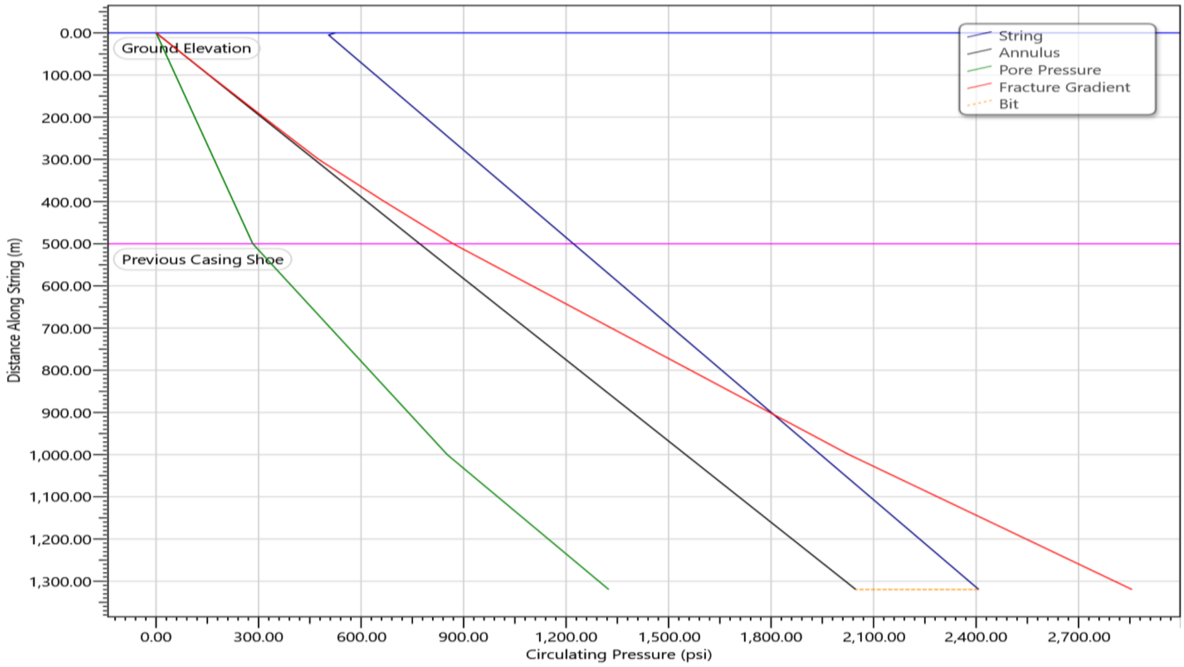


Figure 40. Circulating Pressure vs Depth

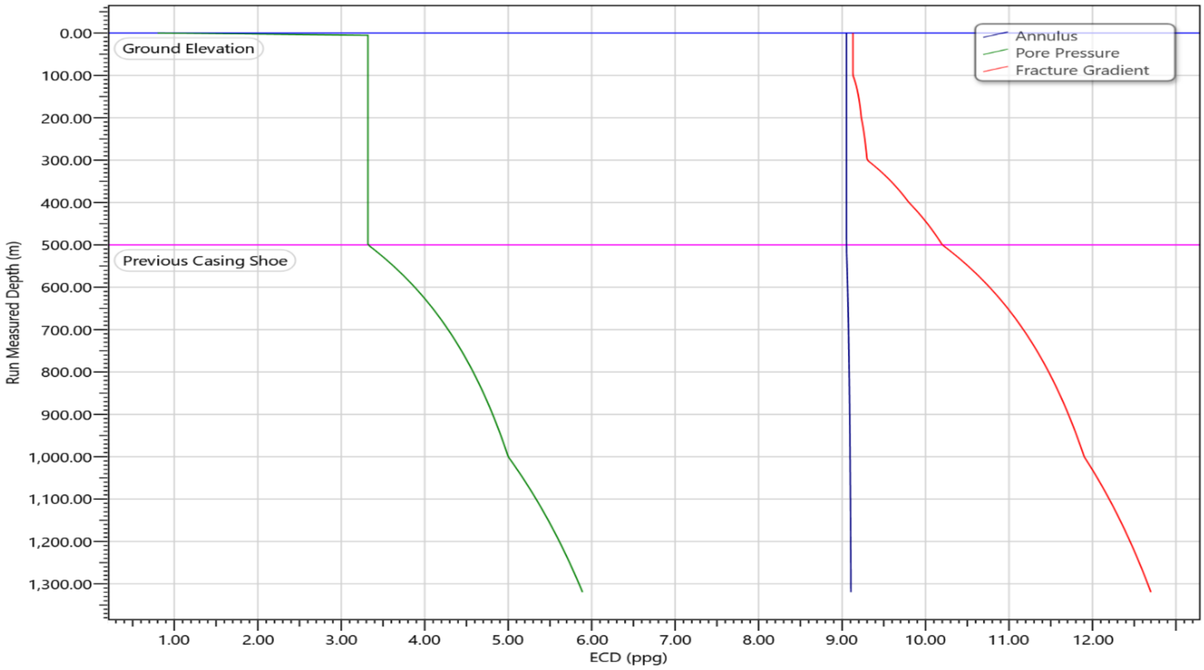


Figure 41. ECD vs Run Depth

Chapter 5 Time and Cost Analysis

5.1 Time and Cost analysis

The primary goal of the project is to reach the hydrocarbon reservoir as economical as it can be, while maintaining the necessary quality and safety for well, environment and personnel.

In order to fulfil the goal, the oil industry is in constantly innovating new methods and technologies or practices to operate and deliver the required work more efficiently, faster and safer. When it comes to applying the technology and get the approval, it shall bring its advantages and prove it is economical, efficient and profitable compared with the conventional method or its peers.

Onshore or land rig day rate is approximately $19000-20000. Thus, it is important to make sure each moment is countable and not wasted in non-necessary or problem-solving operations such as freeing stuck pipe. Using different technologies can help eliminating some of operations that are time consuming and risk raises such when Casing Drilling is being used, tripping operations are eliminated. Thus, huge reduction in time risks and cost cutting which are for pipe use, transporting, and regular maintenance. The drilling pipes that are eliminated when non-retrievable Casing Drilling technology is being applied due to the use of casing pipes itself, they are shorter by length approximately 25%, which helps reducing connections compared to normal drilling pipes. Once TD is reached, no tripping is required since casing is already set, hence, reducing the risks of premature casing seating due to swelling that can occur in conventional drilling or hole caving, where in casing drilling such risks are avoided by having casing already set at TD, this can reduce NPT by 45%.

In order to make the comparison between Conventional drilling method and Managed pressure casing drilling technology to drill the 17 ½" and 12 ¼" sections, a plan has been made to estimate time required for each method and the estimated cost without problems faced in actual project.

All Time and Cost estimation were done using the specialized www.iqx.io platform for calculations and estimations.

IQX is an online platform the provides the option of time and cost estimation of Drilling projects step by step. By inputting the properties of the project, events module, cost module and project risks, it can give a simulation of a detailed prediction for cost and time for the project plan.

5.1.1 Conventional Drilling Plan and Actual Well

In order to plan the well, the following data from the case study have been used to create the time and cost plan:

- Drilling time.
- Casing running.
- Cementing.
- Drilling hazards probability from offset wells. See Appendix B.

Actual well construction Time vs Depth was shown in table 4.

The actual data obtained from the provided report about the actual well were used to create the time depth diagram and for cost estimation for both planned well and actual well.

The Drilling hazards faced during the project were taken into account, also, from the offset wells were considered too.

The following table shows Time break down for planned well and actual constructed well by phase:

Table 22. Conventional Drilling Time Breakdown by Phase

Interval Simulation Statistics - Days	**Planned Well**	**Actual Well**
17 1/2" Drilling	44.58	72.55
17 1/2" Casing Running	2.87	4.09
17 1/2" Cementing	4.82	6.83
12 1/4" Drilling	110.35	196.10
12 1/4" Casing Running	5.39	7.57
12 1/4" Cementing	5.15	7.33
Cumulative Simulation Statistics - Days	**Planned Well**	**Actual Well**
17 1/2" Drilling	44.58	72.55
17 1/2" Casing Running	47.45	75.74
17 1/2" Cementing	52.28	80.62
12 1/4" Drilling	162.63	244.51
12 1/4" Casing Running	168.02	249.87
12 1/4" Cementing	173.16	255.53
Total days:	**173.16**	**255.53**

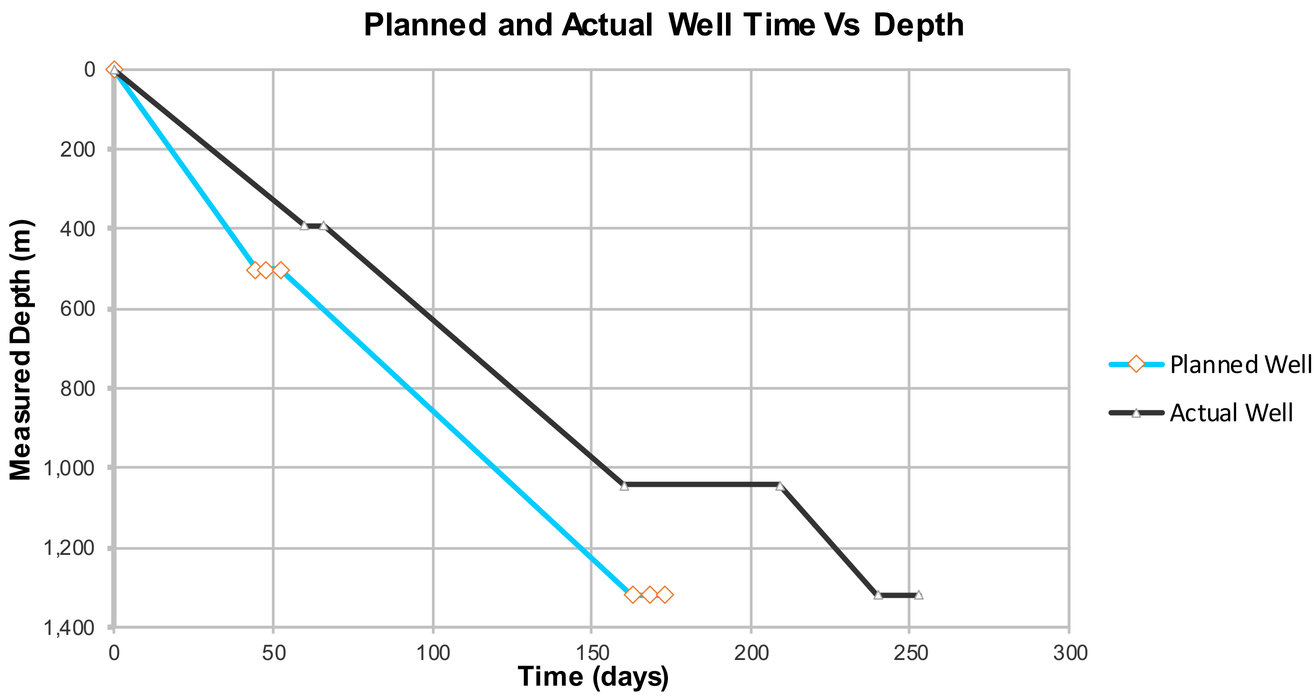


Figure 42. Planned and Actual Well Construction Time Vs Depth

There was no information regarding costs in the report handed with this particular case, thus, different references were used to estimate the operational costs for the Planned well and Actual well construction. The following table shows the cost break down by phase for Planned well and Actual well:

Table 23. Cost Breakdown by Phase

Interval Simulation Statistics - Cost	Planned Well	Actual Well
17 1/2" Drilling	$ 1,143,073	$ 1,834,513
17 1/2" Casing Running	$ 142,332	$ 189,372
17 1/2" Cementing	$ 183,724	$ 234,726
12 1/4" Drilling	$ 2,800,015	$ 4,918,733
12 1/4" Casing Running	$ 361,566	$ 462,268
12 1/4" Cementing	$ 141,321	$ 194,972
Interval Simulation Statistics - Cost	**Planned Well**	**Actual Well**
17 1/2" Drilling	$ 1,143,573	$ 1,835,013
17 1/2" Casing Running	$ 1,285,905	$ 1,998,953
17 1/2" Cementing	$ 1,469,629	$ 2,150,052
12 1/4" Drilling	$ 4,269,644	$ 6,295,777
12 1/4" Casing Running	$ 4,631,210	$ 6,676,439
12 1/4" Cementing	$ 4,772,531	$ 6,835,703
Total Cost:	$ **4,772,531**	$ **6,835,703**

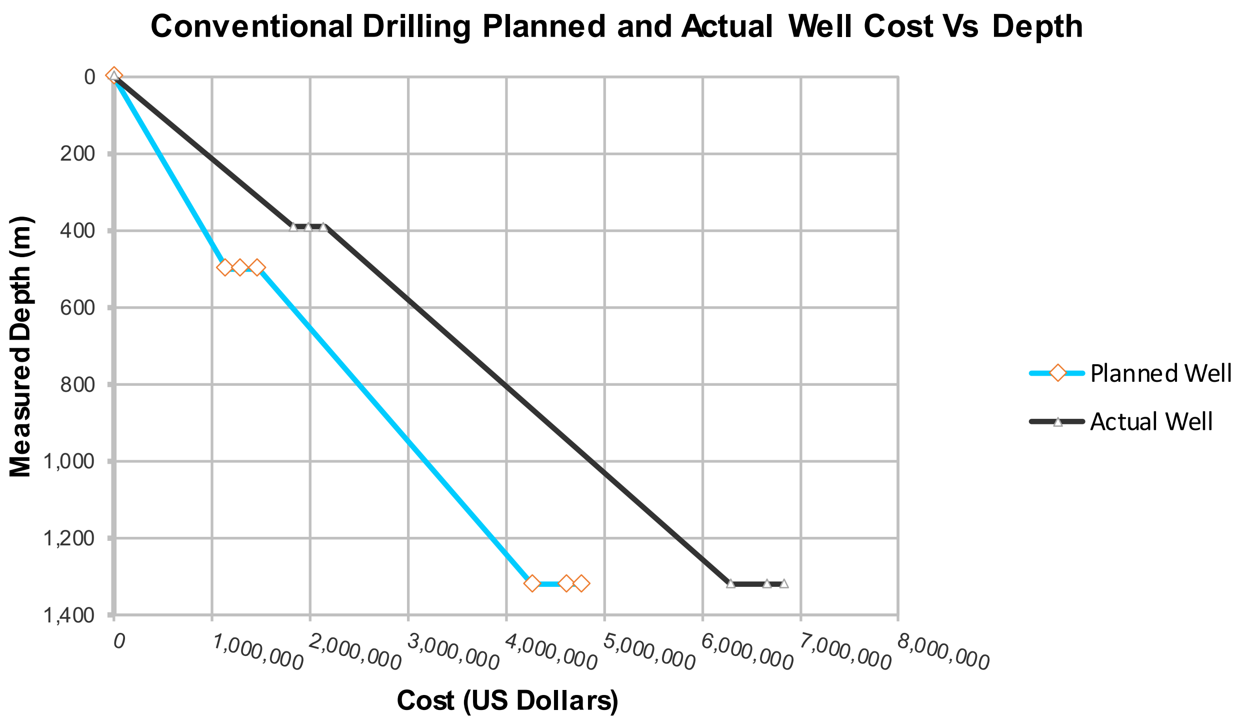


Figure 43. Conventional Drilling Planned and Actual Well Construction Cost Vs Depth

5.1.2 Managed Pressure Casing Drilling

In order to estimate the time and cost while for the Managed Pressure Casing Drilling, case studies have been referred to their actual operational data. Adding to it the drilling hazards in this particular case.

Regarding the 17 ½" section Drilling and Casing phase, they were combined since that while using Casing drilling, there is no need to make an extra operation for casing running. A minimum rate of penetration (ROP) has been set based on the actual well construction of 6 m/h, and a maximum 20 m/h based on the case studies of Casing Drilling technology. For cementing operations, same as in conventional drilling parameters that were used in the case study, in calculations with those parameters there were no problems expected.

The following table contains the time break down by phase used to estimate time for Managed Pressure Casing Drilling.

Table 24. Time Breakdown by Phase for (MPCD)

Interval Simulation Statistics - Days	**P10**	**Pmean**	**P90**
17 1/2" Drilling and Casing	1.65	5.18	11.51
17 1/2" Cementing	0.78	0.80	0.82
12 1/4" Drilling	3.50	15.79	38.32
12 1/4 " Cementing	0.82	0.83	0.84
Cumulative Simulation Statistics - Days	**P10**	**Pmean**	**P90**
17 1/2" Drilling and Casing	1.65	5.18	11.51
17 1/2" Cementing	2.45	5.99	12.32
12 1/4" Drilling	6.41	21.77	41.76
12 1/4 " Cementing	7.25	22.60	42.59
Total days:	**7.25**	**22.60**	**42.59**

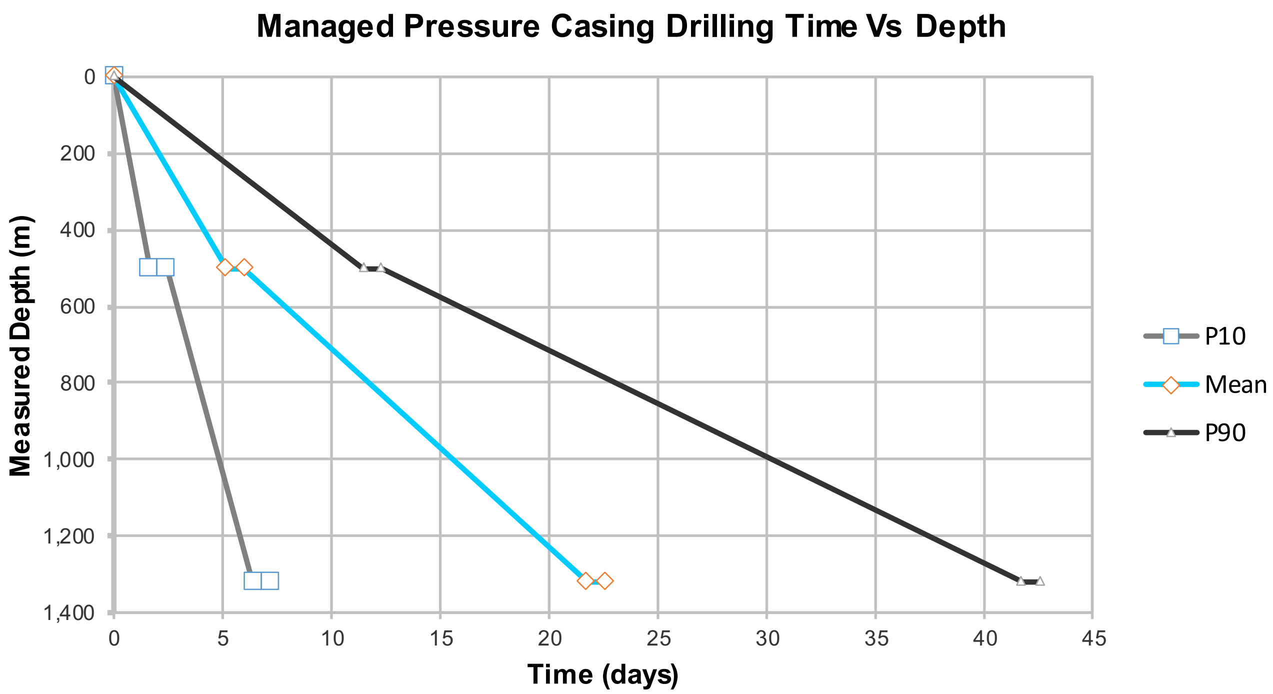


Figure 44 Casing Drilling Time-Depth (MPCD)

For cost estimation, initial costs have to be considered, due to the fact that Casing Drilling technology needs special rig equipment, thus, rig converting costs were added prior to operation costs. The following table contains cost break down by phase:

Table 25. Cost Breakdown by Phase for (MPCD)

Interval Simulation Statistics - Cost	P10	Pmean	P90
Rig Converting	$ 4,623,247	$ 4,751,225	$ 4,877,780
17 1/2" Drilling and Casing	$ 220,357	$ 384,555	$ 678,938
17 1/2" Cementing	$ 102,465	$ 104,009	$ 105,541
12 1/4" Drilling	$ 531,563	$ 1,078,463	$ 2,081,140
12 1/4 " Cementing	$ 166,612	$ 168,006	$ 169,419
Interval Simulation Statistics - Cost	**P10**	**Pmean**	**P90**
Rig Converting	$ 4,623,247	$ 4,751,225	$ 4,877,780
17 1/2" Drilling and Casing	$ 4,882,213	$ 5,135,780	$ 5,482,943
17 1/2" Cementing	$ 4,985,823	$ 5,239,789	$ 5,587,325
12 1/4" Drilling	$ 5,607,236	$ 6,318,252	$ 7,227,388
12 1/4 " Cementing	$ 5,775,245	$ 6,486,258	$ 7,395,699
Total Cost:	**$ 5,775,245**	**$ 6,486,258**	**$ 7,395,699**

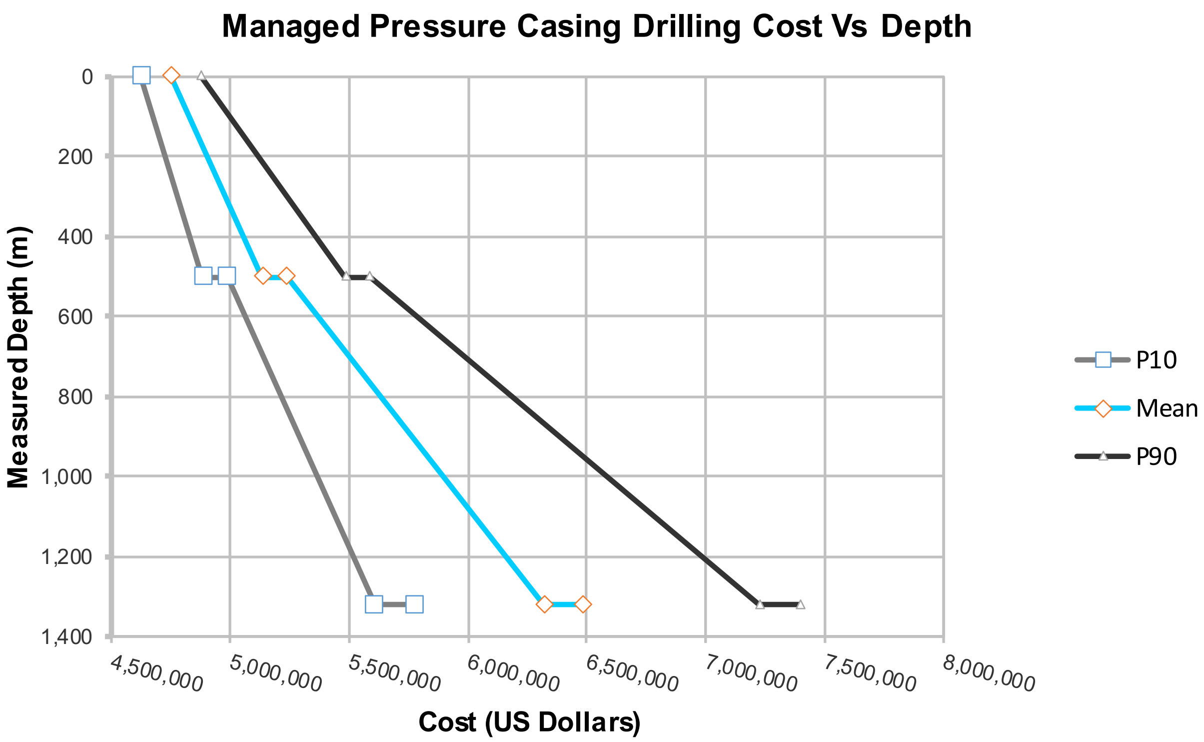


Figure 45. Casing Drilling Cost Vs Depth (MPCD)

5.2 Conclusion

Managed pressure casing drilling implementation in this particular case shows the power of this technological blend, in which both technologies working together to deliver the project in the most efficient way. Casing drilling technology helps eliminating tripping operations, premature casing seating and minimizing stuck problem caused by formation swelling by its plastering effect and total time formation is in contact with fluids. The managed pressure drilling help controlling the well in the sever mud losses or total mud losses which can be risky to continue drilling in case of influx occurring which in one of the offset wells happened in this field.

Based on the cost analysis, the estimated Planned conventional method well construction time is 173 days with $4,772,531 cost approximation, and Actual conventional method well construction cost approximation was $6,835,703 with 255 days of operations were required to reach TD of 1320 m.

MPCD time estimation was a minimum of 7.25 days and 42.59 days to reach total depth of 1320, and an approximate of minimum cost $5,775,245 and maximum cost $7,395,690 to reach TD of 1320 m. Meaning that MPCD is applicable in this particular case due to the high time and costs faced during actual well construction and risk minimizing during operations.

Chapter 6 Conclusion and Recommendations

After analysing the data that was provided by the NPC company about the actual well, it was concluded that the time spent on the 17 ½" and 12 ¼" sections was the major time consuming due the high Non-Productive Time during the well construction.

The problems faced during the well construction of these two sections were the main time and cost consumers while attempts were made to treat and overcome them.

The sever mud losses at several intervals was mainly caused by the natural fractures that those formations have hence, traditional treatment methods like LCM materials were not successful to cure the losses.

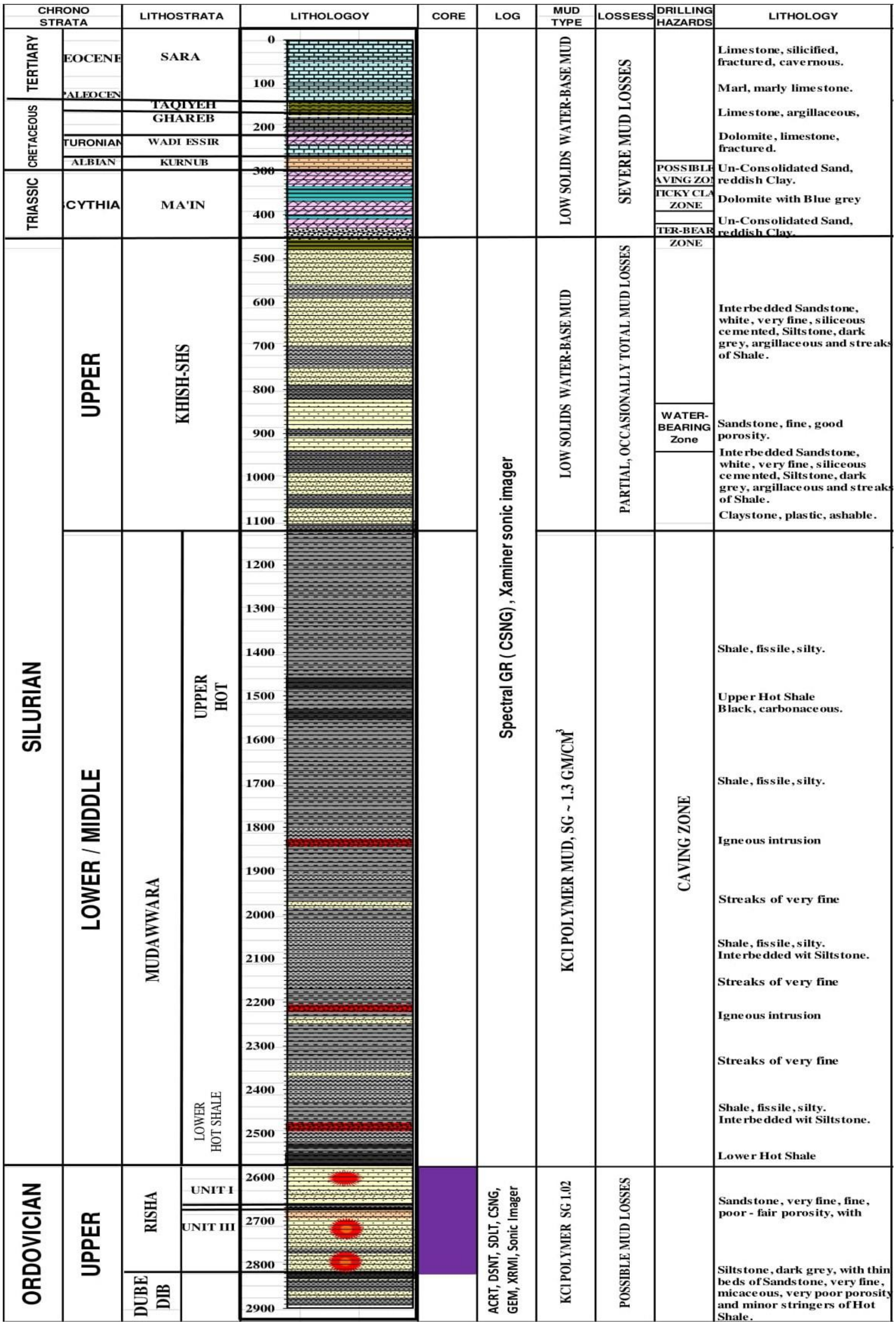
Managed pressure casing drilling was the proposed solution, the two technologies are known to be considered in similar cases where a highly fractured formations are expected to be dealt with.

The time and cost analysis for Managed Pressure Casing Drilling, with the consideration of the drilling hazards and lost time were faced during well construction, proved its applicability in this particular case. Similarly, to case study of Argentina fields, where they had a 53%-time reduction, the time estimated was significantly less than the conventional drilling method that was used to drill the two sections, with approximately same cost.

Managed Pressure drilling technology part in this solution is to maintain the well in a controlled situation when the sever loss of drilling fluid is encountered, which is highly expected to be encountered through the 17 ½" and 12 ¼" sections, and allows a constant monitoring of what is happening downhole. When it is being applied, it is recommended to have large volumes of sacrificial drilling fluid.

The Managed Pressure Casing Drilling can be more economically profitable when it is applied for several new projects are planned to be constructed. Since rig converting expenses are high and are done for one time only. The cost per well will be decreased significantly.

Appendix A Lithology



Appendix B Drilling Hazards

Loss Circulation

Drilling Depth (m)	Loss Depth	OEDP Cement	Loss Type	Formation	Rock Type	Mud Type	Mud weight(sg)	Treatment method
0-46	35		Total	Sara	Limestone	Water Base mud	1.03	Mud plug & Run 20" casing
46-73	46		Total	Sara	Limestone	Water Base mud	1.03	Mud plug (LCM) & cement plug
185-257	192,199	256,199	Total	Wadi Sir, Kurnub	Dolomite, Sandstone	Water Base mud	1.06	Mud plug (LCM) & 2 cement plug
266-290	277	280	Total	Main	Dolomite	Water Base mud	1.07	Mud plug (LCM)
290-420	345		Total	Main	Dolomite	Water Base mud	1.07	Mud plug (LCM)
420-1029	551-572	551-573	Total	Khish-Sha	Dolomite	Water Base mud	1.05-1.07	Mud plug (LCM), use huge quantity of mud plug
	599-639	599-640	Total	Khish-Sha	Sandstone	Water Base mud		
	691-726	691-727	Total	Khish-Sha	Sandstone, Siltstone	Water Base mud		
	760-808	760-809	Total	Khish-Sha		Water Base mud		
	850-877	850-878	Partial	Khish-Sha		Water Base mud		
	1005	1006	Total	Khish-Sha		Water Base mud		
1090	1090	1090	Total	Khish-Sha	Sandstone, Siltstone	Water Base mud	1.07	Cement plug
1117	1117	1117	Total	Khish-Sha	Sandstone, Siltstone	Water Base mud	1.07	Cement plug

Fishing

Depth (m)	TOF	Formation	rock type	Mud type	mud weight	Treatment method
399	141(DP)	Ghareb	Limestone + Claystone	water base mud	1.07	use overshot

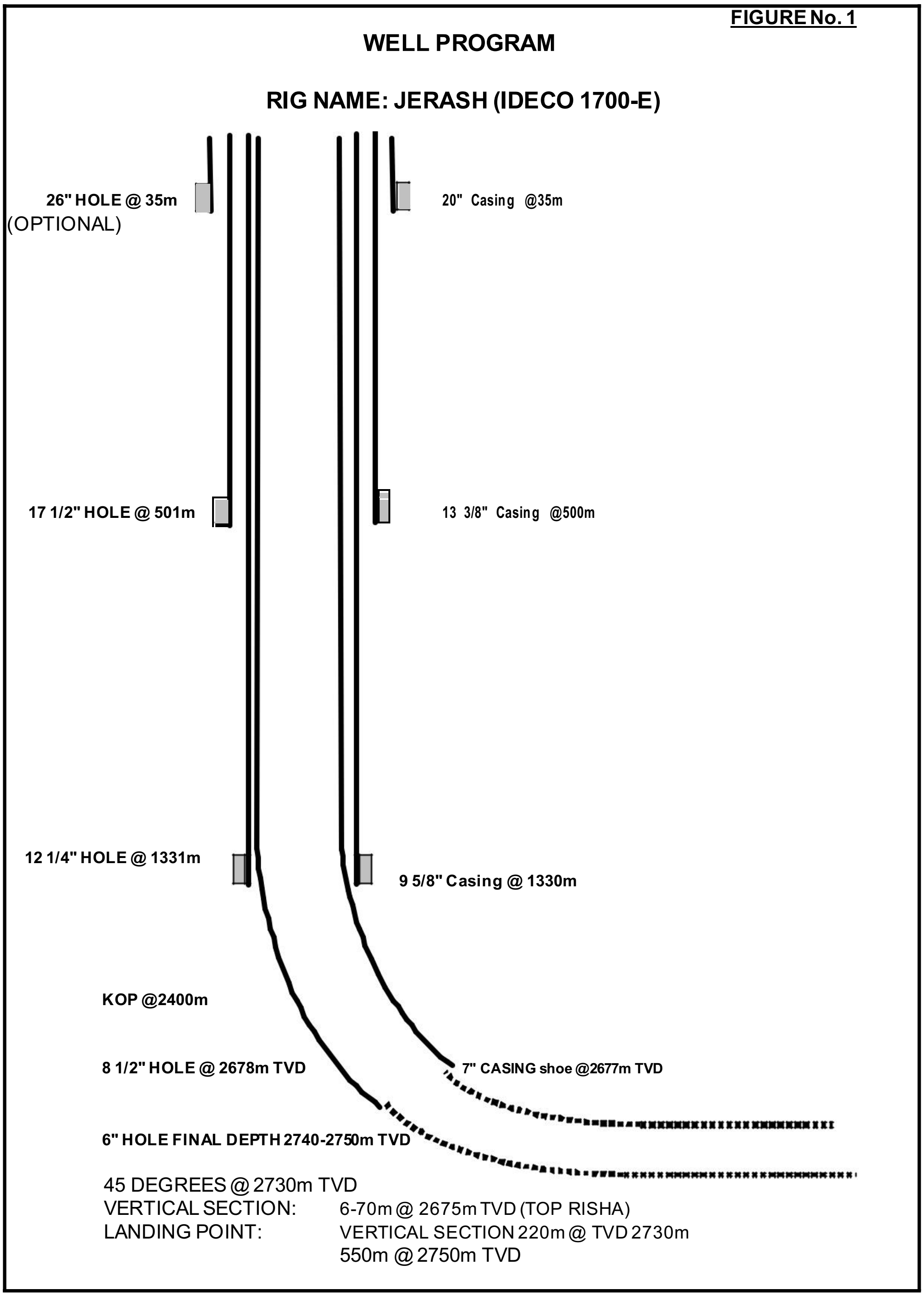
Stuck pipe (Swelling, Tight hole)

Depth m	Formation	Rock Type	Mud Type	Mud weight(sg)	Treatment method
392-399	Main	Dolomite, Clay	Water Base mud	1.08	Increase mud weight, Reaming & pump H.V. mud

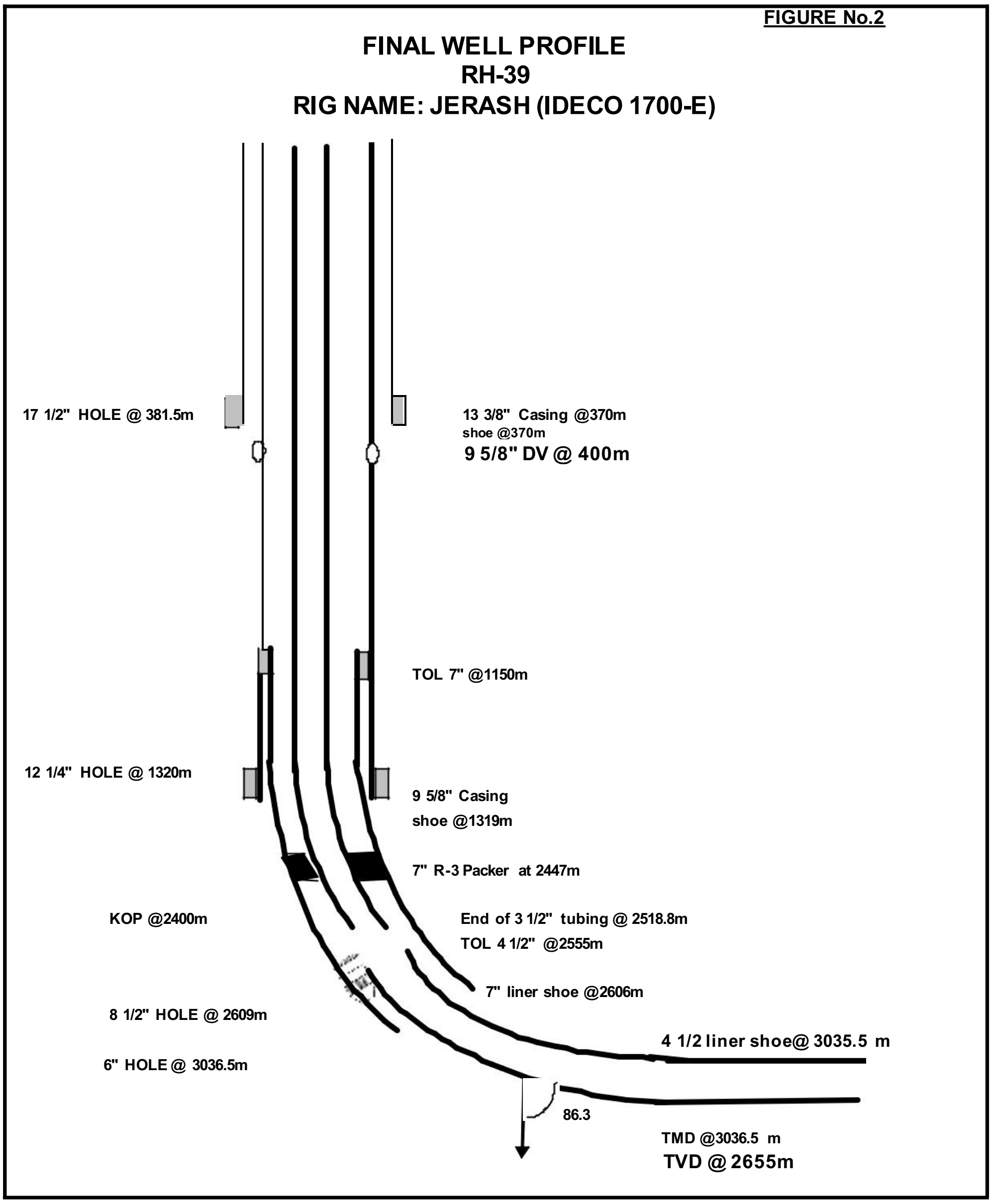
Tight hole (swelling, overpull)

Drilling Depth m	Formation	Rock Type	Mud Type	Mud weight(sg)	Treatment method
687-489	Khish-Sha	Sandstone, Clay	Water Base mud	1.085	Reaming & add crude oil to mud
830-860	Khish-Sha	Sandstone, Clay	Water Base mud	1.085	Reaming & add crude oil to mud
893-896	Khish-Sha	Sandstone, Clay	Water Base mud	1.085	Reaming & add crude oil to mud
1015-1030	Khish-Sha	Sandstone, Clay	Water Base mud	1.085	Reaming & add crude oil to mud
1041-1045	Khish-Sha	Sandstone, Clay	Water Base mud	1.085	Reaming & add crude oil to mud
1102-1212	Khish-Sha	Sandstone, Clay	Water Base mud	1.085	Reaming & add crude oil to mud
1203-1207	Khish-Sha	Sandstone, Clay	Water Base mud	1.085	Reaming & add crude oil to mud

Appendix C Well Program



Appendix D Actual Well



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- (X) Font ArialMT is not embedded. Font ArialMT can not be embedded because: Could not find matching font to embed - 429 more not displayed

Page 95 Results

- (X) Font Arial-BoldMT is not embedded. Font Arial-BoldMT can not be embedded because: Could not find matching font to embed
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Page 96 Results

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Page 96 Results (contd.)

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- (X) Font TimesNewRomanPSMT is not embedded. Font TimesNewRomanPSMT can not be embedded because: Could not find matching font to embed - 35 more not displayed

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