POLITECNICO DI TORINO

Department of Environment Land and Infrastructure

Master of Science

In Petroleum Engineering

Master Thesis

The Enhancement of Drilling Parameters and Mud Properties Through MPD System

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Abbreviations

BHA	bottom hole assembly
ECD	equivalent circulating density
IADC	International Association of Drilling Contractors
C	Constant based on bit type, formation and WOB or slope of shale line
MW	mud weight (Density)
ROP	rate of penetration
RPM	revolution per minute
WOB	weight on bit
TFA	Total flow area
NPT	Nonproductive time
CBHP	Constant bottom hole pressure
UBD	Under balance drilling
CCS	Continues circulation system
RCD	Rotating control device
NRV	Non-return valve
DFIT	Dynamic formation integrity test
DPPT	Dynamic pore pressure test
DC	Drill Collar
D	Depth
SPP	Stand pipe pressure

Dedication

This research work is dedicated to my family and my friends. A special thank you to my Mother who has encouraged me and in every possible way to help me achieve my goals. I also dedicate this work to my brothers and sisters for supporting me and for the wonderful encouraging words while I was working on this research.

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Abstract

Managed pressure drilling systems technique (MPD) have become an important topic of research for drilling engineers due to several drilling problems especially in the extremely deep wells during the past few years. These problems include: well flowing, severe losses, narrow drilling window …and low ROP. Because of these problems, the interest in using and developing the MPD applications have become more vital in onshore and offshore drilling operations. The MPD system provide an opportunity to facilitate the process of drilling wells with quite narrow drilling window and high variation between the fracture pressure and wellbore pressure with less risk. This noticeable importance of MPD was the main drive to have this research to be conducted in order to investigate its impact on drilling parameters and the possible saving in drilling time and cost.

Given data from five wells, which included drilling parameters, well configurations and reservoir information, were used to achieve the object of this research. The drilling parameters in two sections (12 ¼ and 8 ½) were used in Bourgoyne equation to quantify the impact on ROP. The main input data for this equation was the mud density with and without the MPD. Moreover, a Hydraulic software was used to examine MPD impact on the other parameters such as pressure loss and ECD. Later, the new calculated values based on using MPD were utilized to conduct an economic and NPT evaluation to well understand MPD benefits in the case of this research.

After conducting all the calculations on the parameters to understand the impact of using MPD, the results were discussed and MPD usage was found to be very beneficial. ROP was found to be increased with using MPD which is attributed to reducing rock compaction and lowering the density of the mud. Moreover, the pressure losses were found to go down with using MPD. Economic and NPT evaluation indicates a significant saving in time (up to 25 %) and cost can be acquired due to increasing ROP with leads to reduce drilling time. As the required time to drill a section was reduced, overall safety was enhanced, and environmental impact and drilling hazard were minimized.

CHAPTER 1- Introduction

1.1 Drilling Process

The process of reaching an underground hydrocarbon reservoir using drill bits to drill a hole and in turn construct a well is commonly referred to as 'Drilling' in the oil industry (Chavis, 2018). The first record of drilling dates back to the 4th century in China but had reached the rest of Asia and even the middle east by the 8th century. Up until the later part of the 19th century crude oil was only accessible at shallow depths, but this all changed with a new method developed by Edwin Drake which used pipes this in turn allowed for deeper exploration and helped prevent borehole collapse, the method developed by Drake follows us until today. The standard oil drilling process is to initially drill a hole with dimensions of between 5 to 36 inches. A sequence of pipes is used together to dig deeper until the reservoir is reached, these collections of pipes are collectively known as the ''drill string''. In the drilling procedure, there is an essential need of risk management programs for issues with pressure control, blowouts and so forth. Risk management is key in ensuring there is no harm done to the surrounding environment during the drilling procedure; this may include but is not limited to risking the ecological surrounding; air quality and having poor waste management plans. (Tran, Drilling, 2018).

1.2 What is Managed Pressure Drilling (MPD)?

The managed pressure drilling (MPD) is a progressive technique of primary well control that utilizes a closed and pressurized drilling fluid system that permits potentially greater and more accurate control of the annular wellbore pressure profiles than mud weight and pump rate control by itself (TERCAN, 2010). The International Associations of Drilling Contractors (IADC) has defined MPD as "An adaptive drilling process used to accurately control the annular pressure profile throughout the wellbore. The objectives are to determine the downhole pressure environment limits and to manage the annular hydraulic pressure profile accordingly MPD is intended to avoid continuous influx of formation fluids to the surface" (Nikoofard, 2015).By the utilization of managed pressure drilling, the hydrostatic pressure applied in annuals is sustained somewhat above or at balance with the pore pressure all the time during the drilling. In addition, any flow that might happen out of any drilled formation is cautiously controlled and circulated out of the hole by employing the surface equipment. However, the purpose is that an influx from a producing formation is circulated out and the well is in balanced conditions when drilling process is ongoing (Nas, 2008, p. 9)Furthermore, the hydrostatic pressure of mud column in the wellbore should be less than the reservoir fracture pressure to avoid lost circulation of drilling fluids and fracture the reservoir formation (Nikoofard, 2015) MPD has been progressed to treat several problems associated to drilling environments with higher probability for problems such as lost circulation, stuck pipe, wellbore instability and well control incidents where the pore pressure and fracture pressure of the formation is very narrow (mud window). MPD system can provide enhanced rate of penetration (ROP) and reducing the non-protective time (NPT). While applying managed pressure technique a closed loop is formed instead of having open circulation with atmosphere, which allows controlling the surface backpressure. This is controlled by taking the return through a choke manifold that can be adjusted the backpressure and equivalent circulation density (ECD) while dynamic condition (circulation). (Lind, 2017). MPD may incorporate control of backpressure, fluids density (Mud weight), mud rheology properties (PV, YP and gel quality), annular drilling fluids level, circling erosion, and gap geometry. There has not been recorded occurrence of a kick when Managed pressure drilling methods connected. This is not to say have been no problems, sometimes (BHA) Bottom hole assembly still gets stuck and lost circulation problem still happen, but not the same magnitude as in conventional drilling. MPD may permit quicker corrective action to deal with pressure Variations observed while drilling. (Nas, 2008).

1.3 Drilling Window

In general drilling window is the variation between the highest pore pressure and the lowest effective fracture pressure of the formation. Drilling window can be calculated for any section of the interval an open hole. The drilling window should be known for each interval of the well while drilling, to avoid several hole problems related to pore/fracture pressure gradient of the formation such as Wellbore flow or lost circulation and hole collapse. (IADC, 2013). the narrow window between the pore and fracture pressure in Deepwater is resulted through the sedimentation process and lack compaction which produce high pore pressure. Furthermore, the fracture pressure is naturally low because of less overburden due to high column of water instead of heavier sediments. (TERCAN, 2010) In conventional wells operation this narrow drilling window increase the wellbore problems and NPT because of that, the operators started using Managed pressure drilling system (MPD) to improve the drilling operations by minimizing drilling problems (Nas, 2008).

1.4 Why use managed Pressure Drilling?

1.4.1 Avoid Kick and Losses Cycles

In conventional well operations the Hydrostatic pressure which applied by fluid density is designed to provide an overbalanced status always over the pore pressure and below the fracture pressure of the formations to be drilled. This works well in areas where the difference between pore pressure and fracture pressure (wide mud window) is large enough to allow some variation in bottom hole pressures. In the current drilling environments, many operator's companies are drilling more complex and often through depleted reservoirs. Very often in these wells the pore and fracture pressure in a single hole section are very close (narrow mud window). This can result in losses and kicks being taken, resulting in longer well times and additional costs. Managed Pressure Drilling allows more accurate bottom hole pressure control, resulting in fewer pressure fluctuations and it allows better control of the well. (Nas, 2008). Figure 1 bellow demonstrates the drilling pressure windows that is used by the different methods. (Lind, 2017).

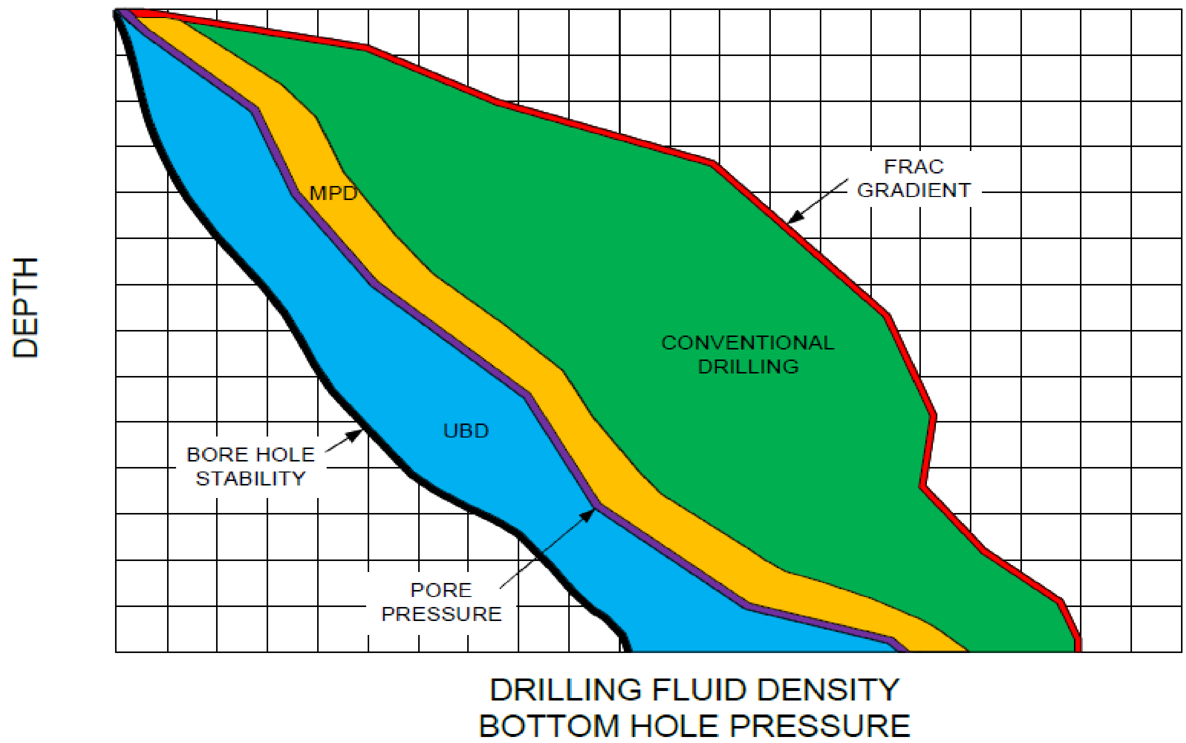

Figure 1- Drilling Window of different systems including MPD, UBD and Conventional Drilling.

1.4.2 Improve rate of penetration (ROP)

It was found there is a direct relationship between the dynamic overbalance and the differential pressure at rock bit interference. When these two parameters go down, the force of a broken rock from the formed position will go down too. That means, the smaller the force and the shorter the time will be needed to displace the broken chip from its original location leading in maximizing the required rate for cutting removal in the hole which causes the ROP of drilling bit to increase as well. Enhancing the rate of penetration is a direct benefit of minimizing overbalance pressure (Anantha Sarat Sagar Nauduri . George Harold Medley, 2009). For instance, in one of the North Sea projects, MPD was utilizing to achieve better rate of penetration and not to exceed formation pressure. This is main target in many projects; however, obtaining such a benefit with MPD is preferred as it is associated with lower risks and safety issues. In general, drillers noticed that optimum penetration rates can be reached when the drilling with low mud Specific Gravity, with decrease the affection of differential pressure between hydrostatic pressure and formation pressure, when the mud density is high will tend to push the drilled cuttings on the wellbore and that will results pore hole cleaning while drilling, this phenomenon has already been described in numerous literatures as chip hold down effect, the variation between the pressure tends to hold the chip in place leading to regrinding in the wellbore which cause increasing in Equivalent mud density and decreasing with rate of penetration while drilling . Garnier and Van Lingen (1959), have shown that static chip hold down pressure (CHDP) limits penetration rate by two mechanisms:

(A) Goes about as limiting weight and Fortify the stone

These two instruments have been depicted to have the most attentive in unconsolidated sands which is predominant in the Niger Delta arrangement.

(B) The differential weight acting over the chip faces its dislodgment.

The figure (2) beneath demonstrates the impact of the differential weight (the distinction between the weight come about by the mud weight and pore weight of the arrangement, at a given level) on the rate of penetration.

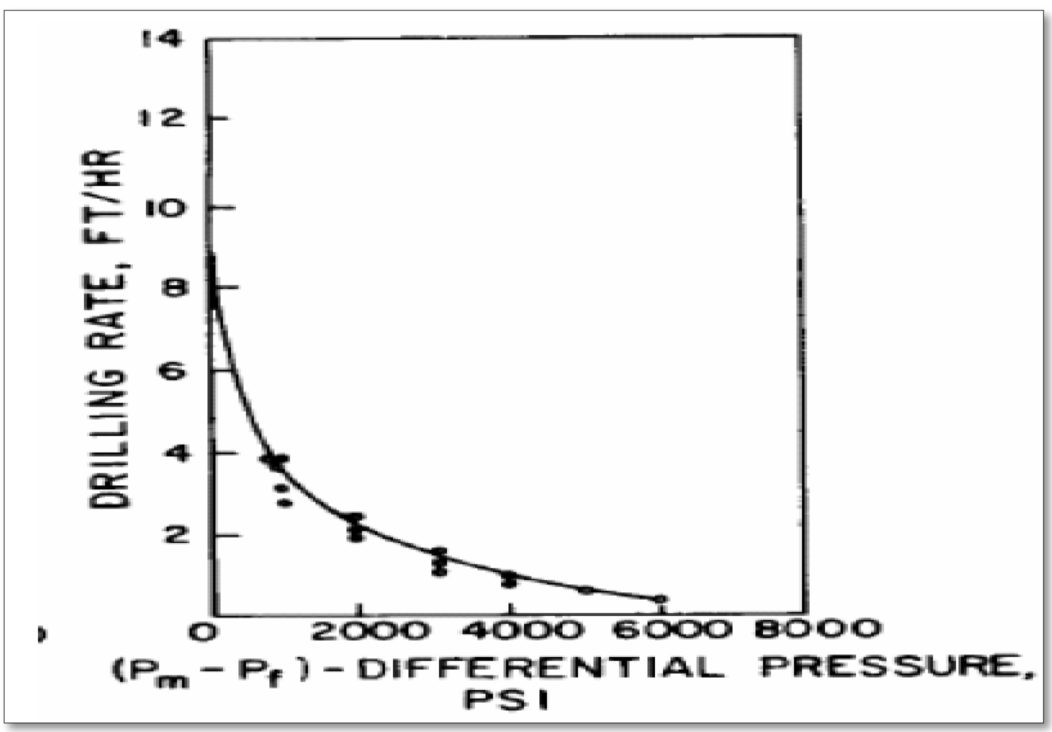

Figure 2 differential pressure impact on rate of penetration

1.5 Other Advantages of MPD

The programmed MPD framework has a few points of interest contrasted with customary Penetrating as takes after:

- Improved well-bore dependability
- In a few conditions, decreasing the quantity of packaging strings required amid each well Enhance HSE.
- with Improvement in wellbeing and well control coming about because of outline that is more point by point, and arranging required for accomplishment.
- Enhance kick and misfortunes identification by observing and recognizing the variety of liquids stream and pit volume.
- Improving admirably bore dependability by decreasing the boring issues like stuck pipe or gap fall.
- Minimizing the danger of lost dissemination.
- Extending control over base opening weight (BHP) to operational situations, for example, associations and trips and when the apparatus pumps are off.
- Minimizing the cost of penetrating liquids utilized while boring by diminishing the liquids thickness. Along these lines, decreasing the cost of synthetic materials utilized extraordinarily the weight up material, for example, barite.
- Identification of gas relocation to surface.
- Check surface breaks and pipe washouts.
- Flag of wellbore breathing or swelling.
- Improved Drilling high weight high temperature arrangement (HTHP)

1.6 MPD technology Applications

MPD has diverse applications in many disciplines with positive and sometime negative impact. The key applications of MPD can be explain in the figure 3.

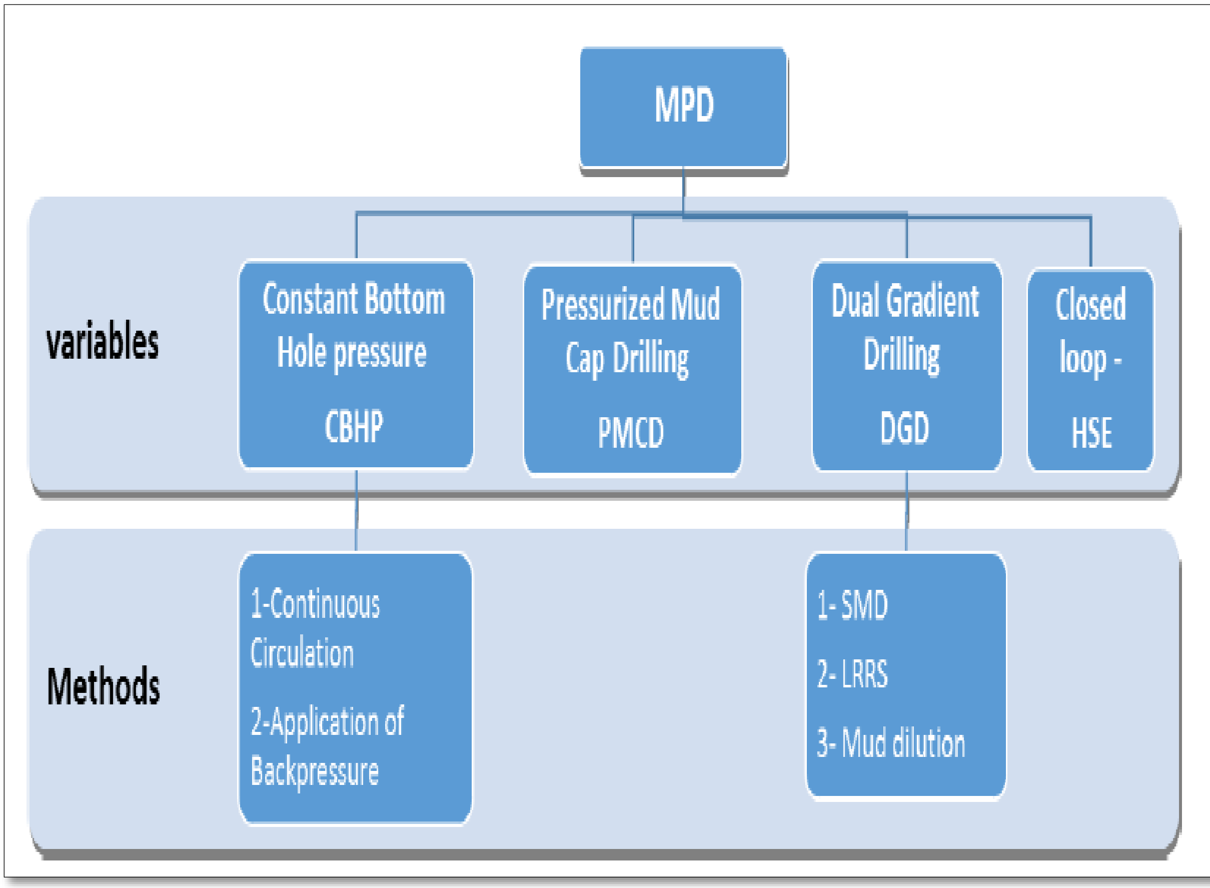

Figure 3-Main application of MPD

1.6.1 Constant Bottom-Hole Pressure (CBHP)

The steady base gap weight technique is a sort of MPD framework utilized with thin penetrating window when the distinction between pore weight and crack weight exceptionally shut, while boring activities, particularly when the mud draw kills while
Association the wellbore weight will change because of the variety of ECD or Annuals erosion weight (AFP) and convergence that can happen when the mud pump begins working again after the association there is an extra weight in the wellbore because of break the mud gel, and that

will build the danger of getting lost dissemination issue. The CBHP framework is attempting to keep these issues, by keeping the wellbore under consistent weight while association by utilizing the stifle weight as an extra parameter endures a superior control of the base gap weight. (Nas, 2008).

1.6.2 UNDER BALANCE DRILLING (UBD)

The possibility of underbalanced repository penetrating to keep the arrangement weight constantly higher than the hydrostatic weight of mud segment to enable the store inflow to the wellbore, and flowed to the surface and be controlled in the surface by the flood control framework. To apply this strategy the hydrostatic weight which exist in the wellbore ought to be lower than arrangement weight by including petroleum gas, nitrogen or air to the penetrating liquids, or the boring liquids outlined officially not as much as the development weight that is mean the underbalance boring status is incited or normal. The mean advantage of utilizing UBD framework to expand the supply efficiency by limiting the development harm. (Nas, 2008).

1.6.3 MUD-CAP METHOD

Mud - Cap technique used to limit the lost flow issues when the boring liquids thickness applied the break weight of the development while penetrating, this strategy connected by utilizing two sorts of boring liquids, the first, substantial mud weight, viscous mud is circulated down the posterior in the annular space to some High over the frail zone. The second boring light mud with low solids substance to abstain from harming the development and furthermore more affordable while boring low weight arrangement (powerless zone), while boring and course, the light liquid and cutting infused into a frail zone up gap beneath the last packaging shoe. The light liquids utilized in Mud Cap strategy can enhance the rate of infiltration due two expanding the water driven pull and less chip hold-down. (Malloy, 2007).

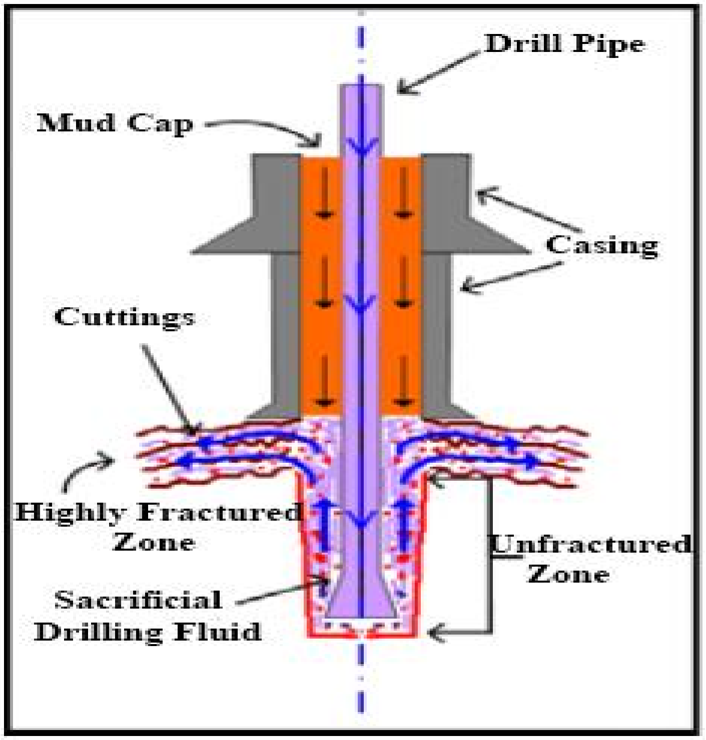

Figure 4-Mud Cap Method

1.6.4 DUAL-GRADIENT METHOD

Drillers have employed double inclination penetrating effectively, principally in offshore industry, where water column is a critical bit of the overburden. Since this fluid overburden has lower density than the normal development overburden, the penetrating window is smaller, in light of the fact that the edge between pore weight and crack weight is restricted. As a result of powerless arrangement quality, Deepwater ordinary penetrating applications more often than not require different packaging strings to maintain a strategic distance from serious lost dissemination at shallow profundities, utilizing single-thickness boring liquids. The goal of the double inclination variety is to imitate the saltwater overburden with a lighter-thickness liquid. Drillers can achieve base opening weight change by infusing less-thick media, for example, idle gas, plastic pellets or glass dabs, into the boring liquid inside the marine riser. Alternative technique is to fill the marine riser with saltwater, meanwhile redirecting and circulating the mud and cuttings from the seabed floor to the surface. These two techniques modify the liquid thickness close to the mud line. Two distinct liquids create the general hydrostatic weight in the wellbore, which abstains from surpassing the crack slope and separating the arrangement. This spares boring activities from spending NPT tending to lost flow is-sues and related expenses. (Malloy, 2007).

1.6.5 Continuous Circulation System (CCS)

CCS is new strategy to hold the well under course even while association notwithstanding hold the well under Equivalent Circulation Density impact always(ECD constant).when the mud pump halted the weight in the wellbore will go down in light of the fact that there is no more ECD impact on the wellbore, because of that few penetrating issue can happen like respectful stuck or fall or stream (development fluids entre the wellbore), CCS additionally can anticipate misfortunes while boring powerless zone when the pump will begin and break the mud gel, at that point create additional weight in the wellbore. This innovation can utilized uncommonly with thin boring window, where the pore weight and crack weight are close.to apply this innovation needs to fix up coupler gadget as appeared in fig 5 . (MARTIN, 2006).

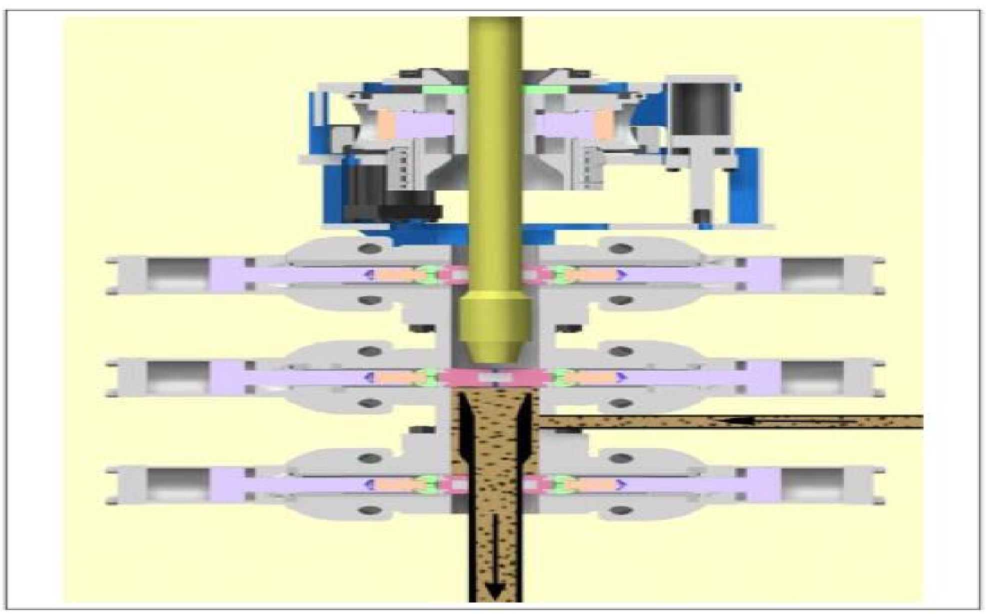

Figure 5 - Continuous Circulation System method

1.6.6 Pressurized Mud Cap Drilling (PMCD)

MPD system might be designed based on different technologies and disciplines. One of the important MPD applications is the Pressurized Mud Cap Drilling. According to the IADC which has described PMCD as a variation of MPD which includes “drilling with no returns to surface where an annulus fluid column, assisted by surface pressure, is maintained above a formation that is capable of accepting fluid and cuttings”. The PMCD drilling application has been established to overcome the difficulties accompanied with drilling in high pressure environment and extremely fractured formation or associated with sour and hazardous gases for instance H_2S. Mitigating the issues of dealing with drilling in highly fractured formations is essential because of the high production potential in such fractured formations and reservoirs. The main challenges during drilling in highly fractured formations are ranging from loss of drilling fluids, hazard associated with possible kick situation, and how to prevent causing undesired formation damage to relatively stable reservoirs. PMCD is a subcategory of Mud Cap Drilling (MCD) technology, which was utilized to deal with extremely fractured reservoirs with the existence of hazardous gases. With the use of mud cap drilling, the loss in the drilling fluids is accepted, however, the nonproductive downtime is prevented. Figure no 6 demonstrated the PMCD method. (Lind, 2017).

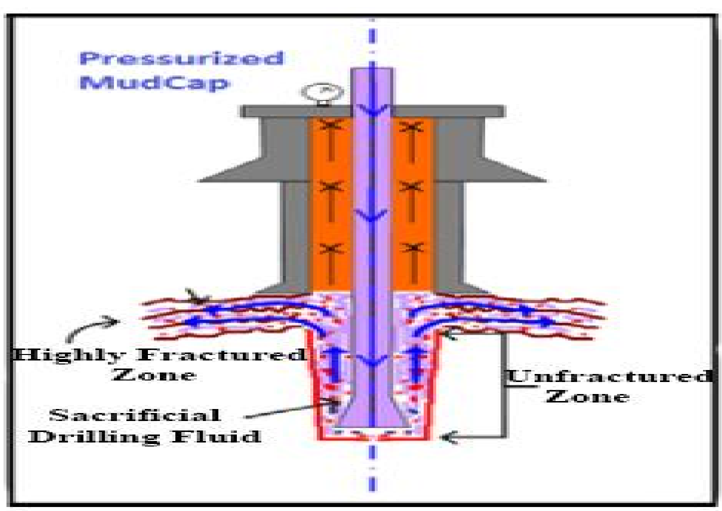

Figure 6 - Pressurized Mud Cap Drilling method

1.7 Equipment for MPD operations

In typical penetrating of ordinary wells, the mud cycle begins from mud direct into bore string then through the annuals of the all-around, went through streamline and the mud return goes to the shale shakers. Be that as it may, while utilizing MPD framework the way of mud return changes, by shutting the HCR valve on the stream line and the mud return coordinated through the MPD gag and two separators. That is make MPD framework the primary control frameworks while penetrating and the BOP framework with gag complex will be the optional well control hardware. The hardware utilized for MPD tasks can be condensed as the following:

1.7.1 Rotating Control Device (RCD)

RCD is a piece of the MPD framework, which is utilized to seal around the penetrate string while at the same time boring and stumbling. This fixing ought to be agent with high-weight territory and diverse penetrate string size. There are two sorts of RCD gadget, Active RCD, which is work by utilizing outside water powered strain to seal the bore string and the other one inactive RCD, which is working by mechanical power due to wellbore weight. Figure no 7 demonstrated the RCD device is utilized in MPD framework. (Nas, 2008).

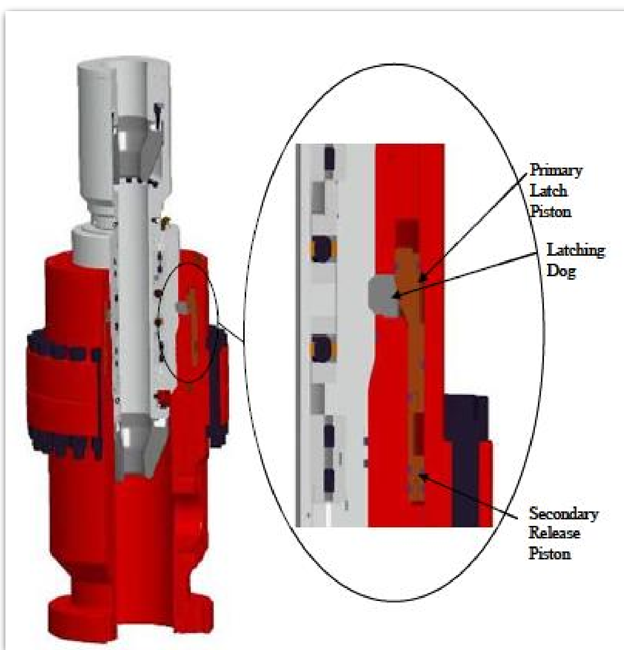

Figure 7- Rotating Control Device

1.7.2 Choke or choke manifold

The choke device is used to control the pressure and the flow of the wellbore in MPD system to prevent continuous kick of the formation fluids. The MPD choke manifold has the ability to be employed either manually or automatically. Figure no 8 shown the choke manifold is used in MPD system.

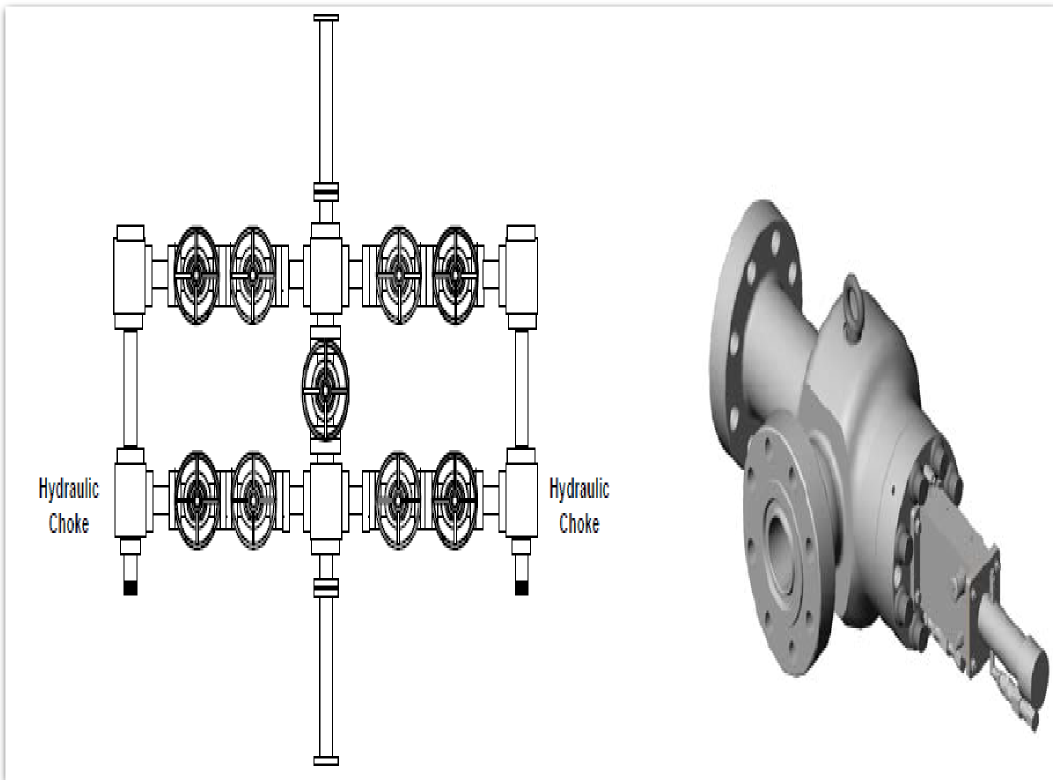

Figure 8 - Choke manifold

1.7.3 Two phase separators

The two-phase separator is used to remove the gas inflow to safe location during drilling operations with managed pressure drilling system. This separator can remove a huge volume of sour gas because this two-phase separator has a gas of 17.5MMscft/day at a working pressure of 125 psi and a liquid capacity 1500 GPM. Figure no 9 shown the two phase separator is used in MPD system.

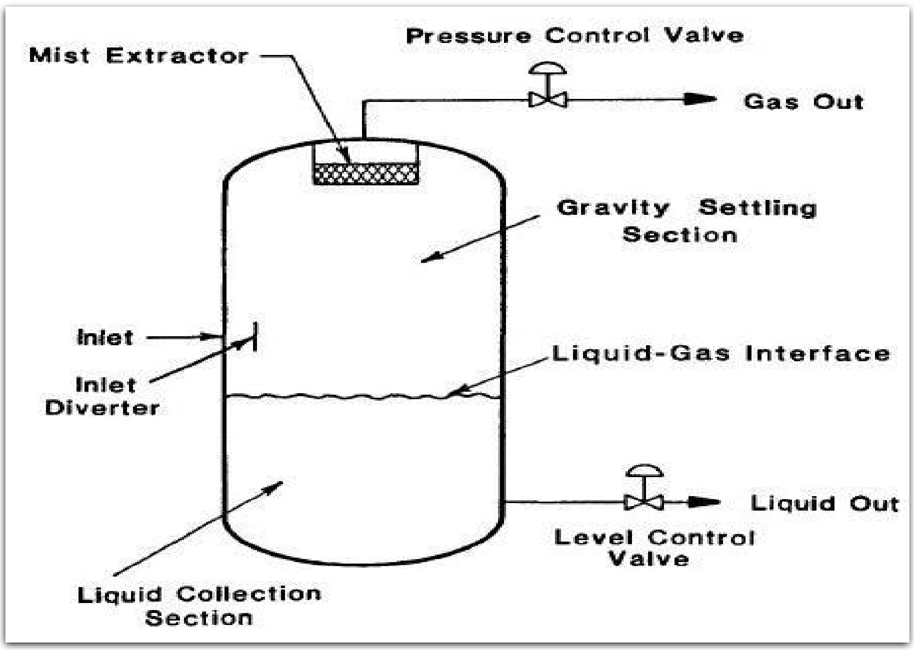

Figure 9- Two phase separator

1.7.4 Data acquisition system

Data acquisition system is important part of MPD system equipment with fully automated control to detect and respond very quickly for any change in wellbore stability by detecting the flow rates and the pressure while drilling. This system is used with narrow drilling window because the small variation between the pore pressure and fracture pressure and avoid the influx or loss circulation while drilling operations. When installed as part of an MPD system, this control system links the choke manifold and system sensors to a real-time hydraulics model and VIRTUAL HYDRAULICS drilling fluid simulation software. In addition, the data engineer of this system should be monitoring the reading of the software in case any change in the parameters will occur while drilling.Figure no 10 demonstrated the Data acquisition system. (Schlumberger, 2018).

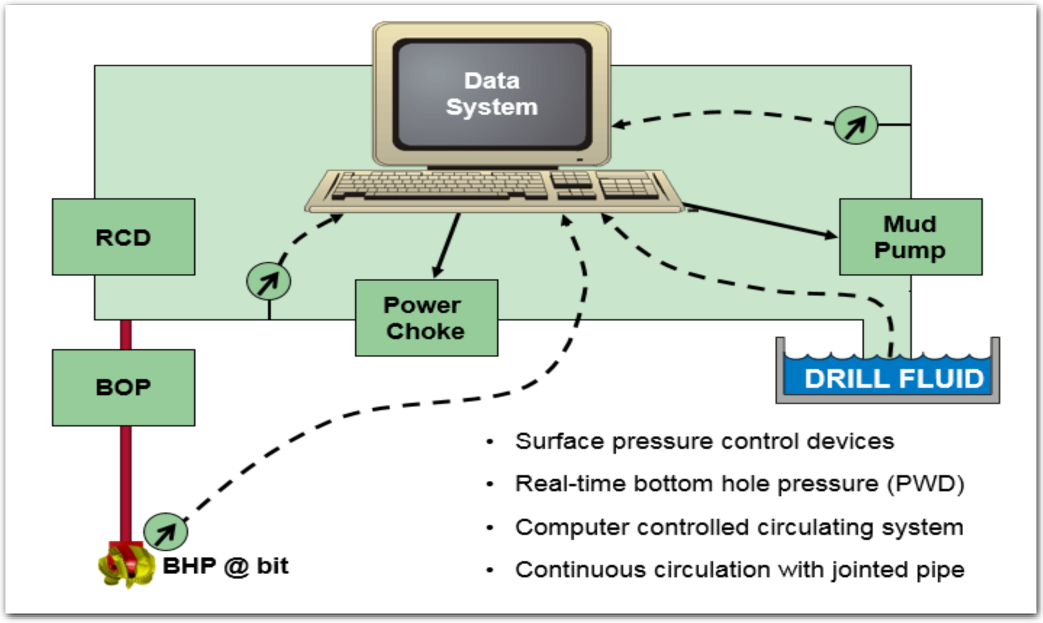

Figure 10- Data acquisition system

1.7.5 Non-Return Valves (NRV)

Non-return valves are essential part for MPD system to prevent kick of fluids inside the drill string. This type of valve usually hooked up in the bottom hole assembly (BHA) specially above the drilling bit to be the first protection point from any influx. Two types of NRV are mostly utilized are the flapper valve and plunger valve. Figure no 11 bellow shown the two kinds of NRV. (Nas, 2008).

Figure 11 - Flapper Valve and Plunger Valve

CHAPTER 2- Literature Review

2.1 History of MPD Concept

The perceptions of employing MPD in drilling operations have been taking into the considerations since the mid 1960 s on US programs of drilling fluids. About 75 % of the US land programs nowadays are drilling at minimum one interval per each well by the use of closed loop circulation technique, which is achieved by employing an RCD (Rotating control device). Different researchers have confirmed that RCD, which is utilized for MPD, has the ability to mitigate the risk of well control incidents. Consequently, many operators' companies requested that the MPD have to be used to choke the mud return from the downhole by enforcing backpressure to exceed well flow and reduce the required time to kill the well while flowing with no need for more time to close the BOP. Nevertheless, that was not possible until MPD concepts were developed to the offshore oil industry in 2003 to deal with the applications of underbalanced drilling technology. The concept was to use devices, applications, which were first invented for under balanced drilling to drill overbalanced with better management in order to control pressure profile in the wellbore, and ECD is kept greater than formation pressure to avoid well flow during MPD operations. (Hannegan, 2015)

2.2 Previous work

As mentioned previously in the introduction of this research, Managed pressure drilling system are considered an interesting topic of research due to minimizing of drilling problems and economic side by reducing the non-productive time also reducing the risk of blow out while drilling operations. For this reason, many researchers have studied the behavior of Managed pressure drilling system while drilling and they have investigated various techniques to improve MPD system and to overcome drilling issues.

R.Soto and fellow researchers investigated about a huge hydrocarbon field named San Joaqin located in eastern part of Venezuela, which is producing 800 mmcfgd. The main problem with this field is the lost circulation while drilling because the narrow drilling window. The average of losses are 2000 bbl./well while a conventional drilling , then Managed pressure system used for five wells drilled in this field with a positive impacted by without lost circulation issue, improving the rate of penetration and minimizing the number of bits used per well . The researcher showed in his investigation between the previous conventional wells were drilled and the fives well with MPD system the enhancement of the ROP by staying over 10ft/hr. to reach 25 ft. /hr., and decreasing the non-productive time while drilling operation by cost saving between 3% to 8 % of the total cost. The potential benefits of MPD techniques were large due to the possibility of minimizing the volume of fluids lost circulation to the formation through the management of down hole pressure. (Reinaldo Alberto Soto, 2006)

Geir Harerland investigated the reduction of the cost while drilling operation between conventionally drilling and managed pressure drilling system. His investigation was on the oil well located in Western Canada, by simulated several scenarios to show the variation in ROP, time of drilling and the cost rate for each meter drilled, also the cost of the drilling fluids by reducing the mud density from 1.4 SG to 0.9 SG (enhanced ROP). His investigation shows that $ 100,000 of the final cost can be saved while using optimizing managed pressure drilling comparing to use optimized conventional drilling The supplementary expenditures to rig in and utilize managed pressure drilling system techniques/equipment is justified. (kustamsi, 2008)

The safety benefits of MPD on land applications were demonstrated in a study conducted by the university of Texas at Austin by Jablonwski and podio) they performed regression analysis to establish a link between the presence of a rotating control device (RCD) and reduce blowout frequency. The study performed three different types of regression analysis and found that there was consistent statistical evidence that the use of RCDs decreased the incidence of blowouts. This finding was observed even though there is natural tendency For RCDs to be deployed on wells, which are inherently more challenging to drill and, therefore, present an increased risk of blowout. The case for MBD as a safety enhancement for well control is further strengthened when considering the case of loss of well control incident. A study conducted by the PSA of Norway (petroleum safety authority Norway, 2011) on incidents on the Norwegian shelf found the three most common major reasons of loss of well control incidents were:

1. Technical failure or not optimal primary barrier /mud column (22%).

2. External reasons-geology and reservoir (19%).
3. Inaccurate kick detection (13%).

All of these triggers are related to unexpected pore pressure. inadequate mud weight or kick detection faliures.in each case, the enhanced kick detection capabilities of MPD would have assisted in mitigation and likely prevented a loss of well control requiring handover to the secondary barrier system (well control equipment).

Additionally, work by Grayson and Gans (Grayson, et al.., 2012) explored some of the following features of MPD applications:

- Overall, reduced probability of loss of well from 1 in 2870,000 to 1 in 6,100.
- Enhanced ability to detect, control and discern well control event.
- Ability to quickly restore the primary well control barrier in the event of influx.
- employing Dynamic Formation Integrity Test (DFIT) and Dynamin pore pressure testing (DPPT) reduces the uncertainty of the operational window constrains, thereby reducing overall risk, and
- Improved ability to identify, manage circulate out riser gas events.

MPD has a proven record of accomplishment of enhancing safety and performance of drilling operation on land. This is achieved through enhanced kick detection and expansion of the primary well barrier capabilities. This handle low severity influxes partially or even fully, reducing the requirement for handover to the secondary barrier system. In this work, the benefits for well control in offsure applications are shown to be even greater than have already been realized on land applications with: 1. Reducing time required to control and circulate out an influx .2. Reduced influx volume as a result of active increase of wellbore pressure on detection, and 4. Reduced peak surface and casing shoe pressure. Although not explicitly shown in the result presented, MPD will also greatly increase kick detection resolution, thereby vastly reducing the influx volume at the time of detection.

A great challenge to realizing these benefits offshore is in ensuring that the surrounding regulations, policies, standards and procedure are not unduly constraining. These policies have been developed in an environment of slow kick detection and limited response options. The conventional well control response, as shown in this work is time consuming can lead to subsequence hole problems. Without MPD, the Low kick detection resolution of conventional technology acts as a filter prevent this response from being deployed unnecessarily. With MPD on board, however, kick detection resolution is significantly enhanced, and a variety of responses is available. In the MPD environment, where even very small influx can be detected, policies must be reviewing to allow an appropriate response. Restricting MPD to drilling and early kick detection can result in not only missing out on the potential benefits offered by an MPD based response, but a vast increase in non-productive time as a result of excessive well control operations. (Partners), 2016).

2.2 MPD and ROP improvement

J.K Foster investigated the improvement of the Rate of penetration in Bullmoose area of North Eastern British Columbia, by studying the well was drilled by Shell Canada. The case study focused about the Nikanassin formation with range from 1000 to 1800 m in thickness, and high pore pressure, which is required high mud weight to control the influx of gas/water while drilling operations. Several companies have been drilled in this field identified this formation as a very hard, slow Rate of penetration (1.4 to 2.4 m/hr.), which increases the Non Productive time, therefore, the cost curves increase. Foster investigation shown the improvement in ROP when managed pressure system applied in this well which incremented the average ROP to 4 m/hr. resulted in using unweighted flocculated water fluids system which help to reduce the solids content in drilling fluids and reducing the hydrostatic pressure on the wellbore during drilling high pressure formation Nikanssin . The lesson learned from Foster case study is the managed pressure drilling system technology can improve the rate of penetration compared to the offset wells (reducing the drilling cost), even with a hard formation and high pressure. He also recommended using MPD technology for future drilling in Bullmoose area (International), 2007).

2.3 Reducing NPT (non-productive time)

MPD system offers a solution to overcome conventional drilling issues of increment a mud system while drilling formation overbalance. MPD practice proves that increasing the mud weight is a significant and unnoticeable non-productive time during drilling operations. Major recordable NPT classifications and key performance indicators used as follow:

1. Tight hole
2. Deviation problems
3. Tool failure
4. Hole cleaning issue
5. Equipment failure and delays
6. Well control
7. Lost circulation

Many drilling engineers observe that the curves of drilling are under severe change demands to reduce the needed time to reach the target depth. Studying the NPT provides both quantitative and statistical drilling programs, cost uncertainties that leads to enhance drilling economics. It was found there is a direct relationship between drilling time and drilling expenditures and in general, reducing drilling time is the key for strategies optimization. Nonetheless, during the drilling process, operators may permit high daily costs in order to lower the overall drilling time, which will lead to cost optimization. (Jeff Saponja | Ade Adeleye, 2006). The importance of MPD is obviously showed statistics of current drilling and problems that currently exist. Figure 12 shows an overview of a database of NPT while drilling offshore gas wells.

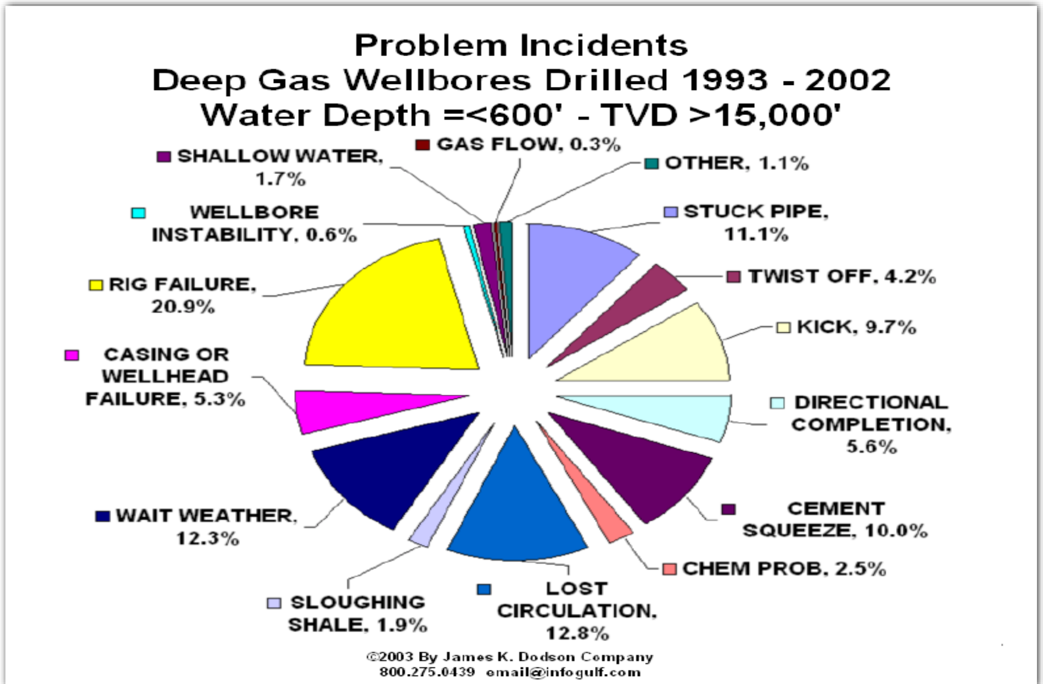

Figure 12- overview of drilling downtime. TVD> 15,000 ft. (Dodson, 2015)

Numerous of non-productive time shows from Fig. 12 especially those related to wellbore instability, and narrow mud window during drilling operations can be reduced by using Managed pressure drilling system (MPD) through controlling the hydraulic pressure in the wellbore greater than the formation pressure and less than the fracture pressure.

Table 1- NPT downtime for TVD> 15,000 ft. (Dodson, 2015)

Lost Circulation	12.8%
Stuck Pipe	11.1%
Kick	9.7%
Twist off	4.2%
Shallow water/gas flow	2.0%
Wellbore instability	0.6%
Total downtime	**40.4%**

At small drilling depths, water or gas can flow into the wellbore when the hydrostatic pressure bellow wellbore pressure gradient. As showed above, a well flow (kick) into wellbore can occur. When the hydrostatic pressure in the wellbore started being lower than the formation pressure, the hole might also reach unstable case and start to collapse on the drill pipe. This may cause the pipe to become stuck (deferential or mechanical stuck) and could lead to a twist off, which is defined as breaking the pipe. The main issue when the pressure applied in the wellbore due to mud column surpasses the fracture pressure-gradient is lost circulation, which is described as losing mud into the formation, and the cost of mixing mud is very high especially when the used mud is an oil base or high-performance mud for drilling. Reservoir damage (skin effect) due to mud invasion into the producing formation can also happen and the wellbore stability become critical. This case study focused about the problems happened while drilling among 10 years and accounted 40 % of drilling problem among this period (1993-2002). There is economic impact shown in table 2 according to these problems, which increased the drilling cost. These hole issues costed the company $98 per foot drilled. MPD can used to reduce the problems are occurring while drilling. MPD system can lower hole cost by about $39 per foot drilled. With wells drilled up to 15,000 ft., that can lead to an average savings of $585,000 per each well. These figures suggested that MPD will decrease the downtime by 40%. MPD will lower these problems, although other procedures could still happen to avoid solving some of these problems. Even if we assume MPD could reduce that 40% to 20%, it could lead to savings of $19.50 per foot, or an average savings of $293,000 for each well which is drilled to a depth of 15,000 ft. (MARTIN, 2006)

Table 2- NPT economics of 102 wells drilled with TVD > 15,000 ft. ((Dodson, 2015)

Total Drill Days	NPT Time, days	NPT %	Dry Hole Cost/Foot	Cost/ft Due to NPT
7680	1703	22	$444	$98

2.4 Bourgoyne equation

Alum Moses investigated the equation of Bourgoyne and Young (1974), and provided a relationship between the changes in drilling fluid density with change in penetration rate while drilling as shown in equation (1). It was found that holding the mud weight to be constant, a relatively higher ROP can be reached due to the reduction in the variation between bottom hole pressure and formation pressure. Bourgoyne equation provided a relationship between the ROP and several major factors including drilling parameters such as; drilling fluid density, rotation rate, and weight on bit. Figure 13 explain the main parameters that have an effect on the ROP. This equation supplies us with a method to compute the ROP at any given depth of the interval. Managed pressure drilling system technique can allow to drill with minimum mud weight required to control the borehole pressure by compensate the hydrostatic pressure applied by mud column. This can be achieved through chocking the return of drilling fluids by using the choke manifold, which is a key part of MPD system. (Moses A. Alum, 2011)

$$\mathbf{ROP_2 = ROP_1}\ e^{cD(MW_1 - MW_2)} \quad \ldots (1)$$

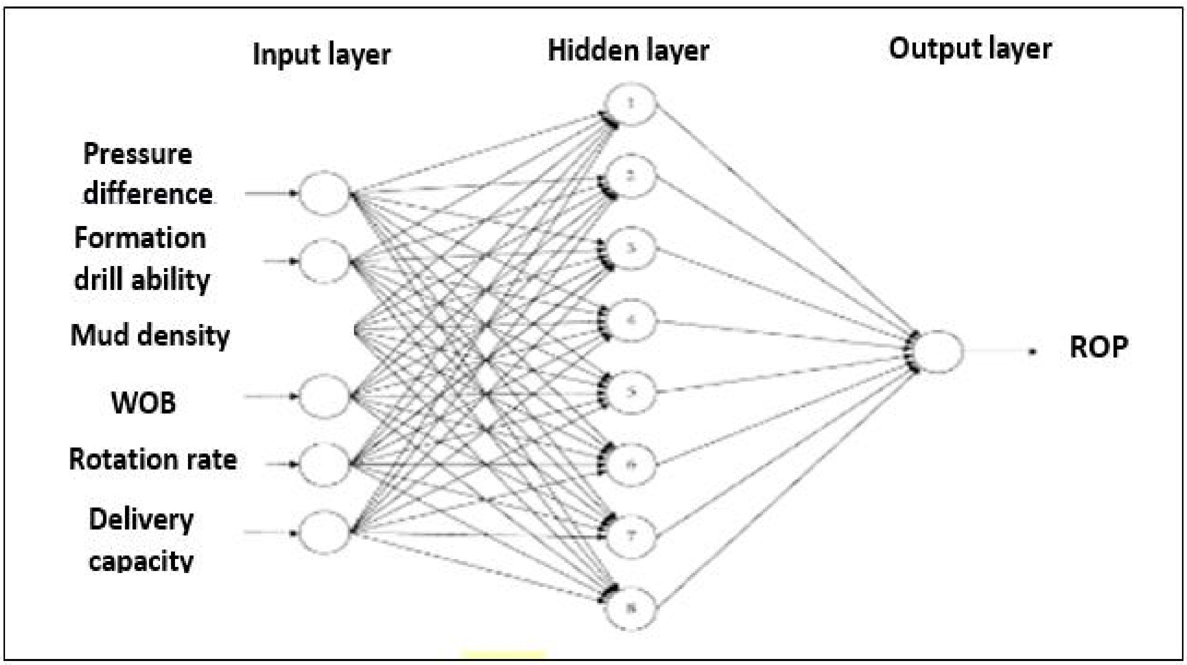

Figure 13- Architecture of ROP predictor system

CHAPTER 3- Methodology and Calculations

The purpose of this study is to investigate the impact of using managed pressure drilling system technique on drilling parameters specially the rate of penetration. To approach the objectives of this study, five wells are analyzed the effect of increasing ROP on well time and drilling cost by reducing the drilling fluids density which used while drilling 12 ¼" and 8 ½" intervals .In addition, this study shows the effect of using MPD on pressure loss in bottom hole assembly among the intervals.

3.1 Data Acquisition

To achieve the goal of this study, data from five wells drilled with conventional mud motor technology have vertical shape of the same field in the south of Iraq was utilized. The data included the wells design, drilling parameters, reservoir characteristics and lithology of the formation drilled.

3.1.1 Field background

It is considered a green field; it has six production wells targeting Mishrif and Yamama Reservoirs. The preliminary plan proposes drilling 14 more wells targeting the same reservoirs. That is being said, the lessons learned from the current wells can be later applied in the future wells, which will help to increase the efficiency of drilling and minimizing the cost.

3.1.2 Geology

3.1.2.1 Field Geology

Table 3- Lithological Prognosis and Geological Column

GEOLOGICAL TIME SCALE				STRATA		
ERATHEM	**SYSTEM**	**SERIES**	**FORMATION**	**TOP**	**THICKNESS**	**LITHOLOGY**
		RECENT	ALLUVIUM	0	14	Recent deposits of alluvium
C E N O Z O I C	**TERTIARY**	PLIOCENE-M. MIOCENE	**U. FARS**	-14	929	Marl facies including alternation of marl, sandstone and few Anhydrite near the bottom.
		M.MIOCENE	**L.FARS**	-943	380	Consists of alternation of Anhydrite layers, red and grey claystone (in the upper part) and layers of shale and thin layers of limestone white at bottom. No salt is expected.
		L. MIOCENE-OLIGOCENE	**GHAR**	-1323	201	Thick layers of Sandstone grey brown transparent w/layers of Claystone brown to red, grey, and thin layers of limestone.
		EOCENE	**Pabdeh**	-1524	87	Sequence of gray argillaceous limestone layer, locally with glauconitic, yellow to white, and dark brown to brown limestone. The top part of the formation consists of gray marl with limestone intercalations and at the bottom, cherty limestone appears.
		EOCENE	**DAMMAM**	-1611	105	Consists of Limestone light grey, creamy, moderately hard glauconitic and Dolomite brown to grey rarely Anhidrotic.
		PALEOCENE	**UMRADHUMA**	-1716	393	Limestone grey argillaceous soft to moderately hard, it is disconformable over Tayarat fm.
Mesozoic	**C R E T A C E O U S**	L.MASTRICHTIAN	**TAYARAT/SHIRANISH**	-2109	167	High glauconitic Marl light grey w/ Limestone argillaceous. Limestone tongue buff soft to medium hard could be encountered.
		L.MASTRICHTIAN	**HARTHA**	-2276	297	Limestone buff hard, dolomitic locally vuggy w/ Limestone grey argillaceous.

		SANTONIAN L.CAMPAINIAN	**SADI**	-2573	87	White to brown Limestone medium to hard chalky porous, Pellety in places w/ glauconitic grey claystone, chert nodules are reported toward the bottom.
		CONIACIAN-SANTONIAN	**TANUMA/KHASIB**	-2660	14	Consists of claystone and thin shale bed w/Limestone grey shaly
		CENOMANIAN – L. TURONIAN	**MISHRIF/ RUMAILA**	-2674	317	Limestone medium to hard buff, creamy and brown w/ Limestone grey argillaceous, sometimes bituminous and pyritic, presence of rudest reef debris are reported.
		U. CENOMANIAN	**AHMADI**	-2991	143	Limestone light grey soft to medium shaly grey to black fissile w/ thin beds of shale grey.
		ALBIAN	**MAUDDUD**	-3134	209	Limestone light grey medium to hard, detrital w/ Limestone grey soft marly.
			NAHR UMR	-3343	179	Shale bituminous, dark grey to black, pyritic and limestone grey argillaceous in the middle part w/ layers of small grains Sandstone grey and shale grey hard pyritic. The lower part of this formation consists of dark gray and gray claystone, brown to dark brown shale and fine to coarse grained sandstones.
		U. APTIAN	**SHUAIBA**	-3522	173	Limestone buff to brown, crystalline sugar grain oolitic in places, dolomitic w/ Limestone light grey argillaceous toward the bottom. It is disconformable over Nahr Umr.
		BARREMIAN -LAPTIAN	**ZUBAIR**	-3695	201	Consists of shale grey green and claystone silty with two thick layers of Sandstone, small grains buff to brown with oil shows.
		HAUTERIVIAN	**RATAWI**	-3896	103	Limestone creamy hard and Limestone grey argillaceous shale w/ thin beds of shale dark grey.
		VALANGINIAN	**YAMAMA**	-3999	424	Limestone buff to brown porous, slight to medium hard, pellety, pyritic, crystalline, bituminous, oil shows and Limestone grey argillaceous toward the bottom.
		BERRIASIAN	**SULAIY**	-4437	In part	Limestone grey argillaceous.

3.1.2.1 Target Formation Geology

A. Mishrif:

Mishrif reservoir is comprised mainly from limestone, which is interbedded by claystone. Mishrif LIMESTONE was found to be grayish white to light gray and fine to very fine crystalline. It is moderately hard therefore, it is firm in part and dolomitic in other parts with traces of free pyrite with visible porosity and decent oil show.

B. Yamama:

Yamama reservoir is comprised mainly from LIMESTONE Interbedded with thin beds of ARGILLACEOUS LIMESTONE. Yamama Limestone was found light brown, beige to cream, occasionally dark brown, fine to very fine crystalline, it is moderately hard therefore, it is slightly dolomitic, argillaceous in part, spotted with organic materials in part, bituminous in part, poor to good visible porosity in part, 20% with inter-crystalline porosity, good oil shows.

3.1.3 Reservoir Summary

The main source facies of Iraq are found within the Jurassic rocks of Sargelu, Naokelekan and Gotnia formations. Most of these Jurassic source rocks have already reached or passed peak oil generation stage. Uplifts in the Miocene locally terminated hydrocarbon generation from these source rocks in northern parts of Iraq. Sargelu and Naokelekan formations are considered, to be the most important source facies in Iraq. These formations contain organic-rich source facies, generally Type II kerogen and have a mean TOC of 5 wt. %. The Yamama formation source rock due to recent studies is Balambo formation deep in the Mesopotamian Basin, where Yamama formation grades eastward into lower part of Balambo formation of Tithonian - Barriasian in age. The organic matter is of marine or mixed origin, with some of plant remains of continental origin. The amount of total organic carbon (TOC) in the Balambo formation. Reaches max 8.8% by weight and the hydrocarbon potential ranges Between 2 and 50 kg HC/ton of rock. The Balambo formation entered the thermal maturation zone and started generating oil during the early Miocene. The late Cretaceous Mishrif Formation mainly consists of shallow-marine massive carbonates and is one of two main oil reservoirs in this field. Regionally, the Mishrif Formation is developed in two major facies: massive platform carbonates containing rudists, gastropods, pelecypods and rich microfauna; and a deeper-marine basinal facies of thinner-bedded, fine grained, dark colored argillaceous Oligostegina limestone with pelagic microfauna. Around 300m thickness of carbonate was penetrated by well X1; with the net pay about 100m. The Yamama formation, more than 400 m thick, is of early Cretaceous age. It is regionally known as a massive oolitic to pellety limestone. Mudstones and marls of Ratawi formation in SE Iraq seal the Yamama formation. For Mishrif formation, the shaly Khasib formation is as a regional seal.

Reservoir data

There are two main production layers within this reservoir Mishrif and Yamama formation. The tables bellow show the characteristic of the reservoirs.

A. Mishrif Reservoir

Table 4- Mishrif Reservoir Properties

Reservoir	Mishrif
Depth, MD\TVDSS(m)	2688/ -2674
Porosity (Dec.)	10%-20%
Contact, TVDSS (M)	-3000 ODT
Hydrocarbon Type	OIL
Gravity (°API)	20.2 °API
GOR (scf/stb)	200 scf\bbl
H_2S (ppm)	2000-3000 ppm
CO_2 (%)	6%
Reservoir Pressure (psi)	Circa 5500 psi
Reservoir Temperature (°F)	205 °F

B. Yamama Reservoir

Table 5- Yamama Reservoir Properties.

Reservoir	Yamama
Depth, MD\TVDSS(m)	4013/ -3999
Porosity (Dec.)	10%-20%
Contact, TVDSS (M)	-4360 (logs) at Zone Yamama D in well X4
Hydrocarbon Type	OIL
Gravity (°API)	35 °API
GOR (scf/stb)	1100 scf\bbl.
H_2S (ppm)	700 ppm in YA 3000-5000 ppm in YB
CO_2 (%)	2-2.5%
Reservoir Pressure (psi)	Circa 8800 psi in Yamama A; Circa 9200 psi in Yamama B
Reservoir Temperature (°F)	285 °F

3.1.4 Well Design

Wells in this field are all cased all the way to the target formation. Five casing types were used in completion the wells in this field and they are listed below in details:

- **30" Conductor**

  To isolate potentially unconsolidated and reactive shallow formations.
- **20" Surface Casing**

  To isolate potentially unconsolidated and reactive shallow formations, Provide support for the wellhead and the BOP Equipment.
- **13 3/8" Intermediate Casing**

  To provide sufficient shoe strength for 25 bbl. kick tolerance in the 12 ¼" section.
- **9 5/8" Production Casing**

  To provide sufficient shoe strength for 14 bbl. kick tolerance in the 8 ½" hole section. Provide a ranging target for relief well drilling if required. In addition, it isolates Zubair and Ratawi from Yamama Limestone for the purpose of a potential abandonment or suspension.
- **7" Production Liner**

  To allow the perforation System: TCP or Wireline and Hydraulic Isolation.

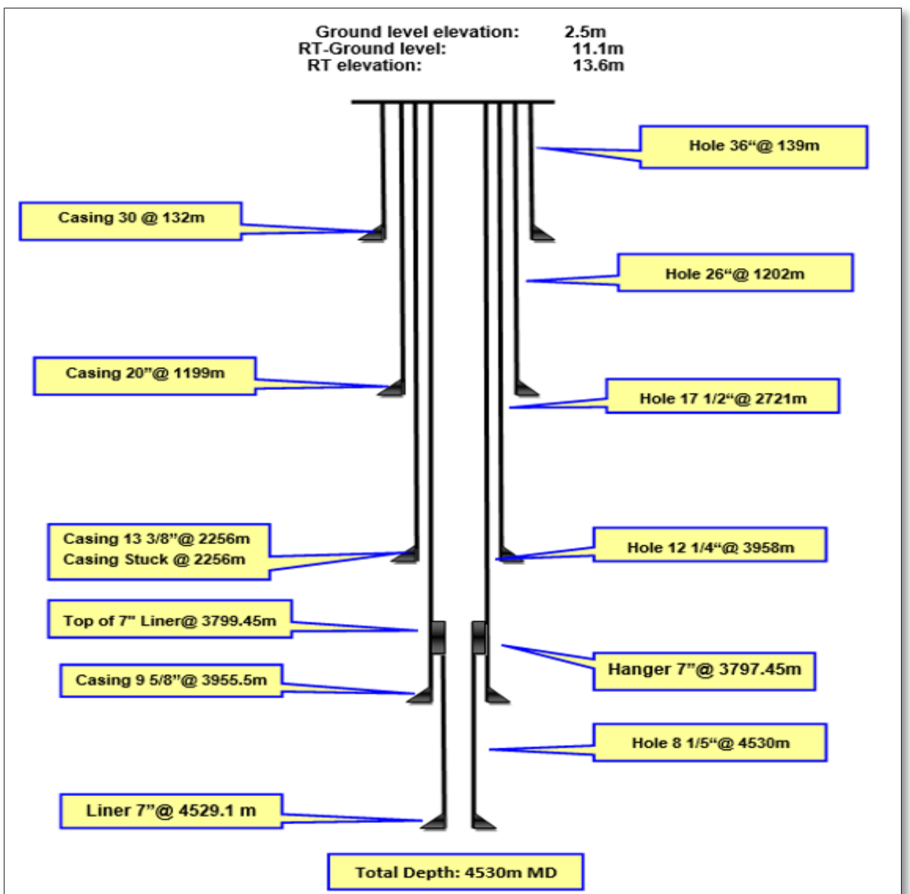

Figure 14 - Well Schematic

3.1.5 Bottom Hole Assembly (BHA)

The bellow tables show in detail the main parts of the bottom hole assembly which were used in the majority of the wells that were drilled in the field that is studied in this research. Table 6 for 12 ¼" interval BHA while table 6 explain the 8 ½" interval BHA.

Table 6 Bottom hole assembly 12 ¼" & 8½" Sections

Item #	Item Description	Qty	Item length (m)	Body OD (in)	Body ID (in)
13	Drill Pipe	1	9.49	5.00	3.250
12	HWDP	15	9.49	5.0	3.250
11	Drill Collar	3	9.45	8.250	3.75.0
10	Drilling Jar	1	10.06	8	3.00
9	Drill Collar	8	9.45	8.250	3.750
8	8 1/4" PBL sub	1	3.87	8.250	3.00
7	Drill Collar	1	9.45	8.00	3.250
6	MWD System	1	10.73	8.00	3.00
5	Roller Reamer	1	0.24	8.00	2.81
4	Drill Collar	1	9.45	8.25	3.750
3	Stabilizer	1	2.13	8	2.810
2	Drilling Motor	1	10.30	9.637	2.25
1	PDC Bit	1	0.33	12.25	3

Item #	Item Description	Qty	Item length (m)	Body OD (in)	Body ID (in)
13	Drill Pipe	1	9.52	5.000	3.750
12	HWDP	15	9.45	5.000	3.000
11	Drill Collar	4	9.45	6.750	3.000
10	Drilling Jar	1	10.06	6.500	2.750
9	Drill Collar	10	9.45	6.500	3.000
8	8 1/4" PBL sub	1	2.73	6.750	2.500
7	Drill Collar	1	5.99	6.750	2.000
6	MWD	1	9.45	6.750	3.500
5	Roller Reamer	1	0.18	6.500	2.250
4	Drill Collar	1	9.45	6.500	3.000
3	Stabilizer	1	2.13	6.500	2.250
2	Drilling Motor	1	8.50	6.750	1.500
1	PDC Bit	1	0.29	8.500	3.000

3.1.6 Drilling parameters

The general drilling parameters in the five drilled wells within 12 ¼" and 8 ½" intervals can be found bellow in the tables 7.

Table 7 Drilling Parameters of 12 ¼" & 8½" Sections

Drilling parameters	Min.	Max.	Ave.
Torque (ftlb)	2000	16000	6000
Weight on bit (ton)	3	12	7
Mud weight (ppg)	10.3	13.5	13
ECD (ppg)	10.6	13.8	13.3
SPP (psi)	2000	5000	3800
Pump rate (GPM)	600	1000	800
ROP (m/hr.)	0.5	11	4
RPM	40	120	80

Drilling parameters	Min.	Max.	Ave.
Torque (ftlb)	2000	12000	6000
Weight on bit (ton)	3	14	8
Mud weight (ppg)	14.3	14.6	14.5
ECD (ppg)	14.5	15	14.8
SPP (psi)	2600	4800	3700
Pump rate (GPM)	400	600	550
ROP (m/hr.)	0.6	9	3
RPM	40	120	80

3.1.7 Drilling fluids types

The drilling fluid was used for drilling in this field is water base mud (WBM). The mud weight in the target sections ranges from 11 to 15.2 ppg. The used mud was provided with maximum chemical inhibition for Shale formation, which is characterized by its sensitivity to water base drilling fluids, and its tendency to create bit balling problems & mechanical sticking issues due to its hydration. More details regarding the drilling fluid properties by interval sections can be found in table 8:

Table 8-Mud properties for 12 ¼" and 8 ½" Sections

Mud properties	Units	12 ¼"	8 ½"
Mud Type:		**WEL-DRILL CPG** **KCL/PHPA/GLYCOL Mud**	**WEL-DRILL RDF** **NACL Polymer Mud**
Density	PPG	11 – 13.5	14.2– 15.2
Viscosity	Sec/Qt	45 – 55	45 – 55
PV	Cps	25 - 60	50 - 75
YP	lbs/100 ft^2	20 – 25	20 - 25
VG 6 rpm		>8	>8
Gel (10 Sec)	lbs/100 ft^2	4 - 8	4 - 8
Gel (10 min)	lbs/100 ft^2	8 - 12	8 - 14
API Fluid Loss	cc/30 min	< 5	< 5
HTHP Filtration	cc/30 min	< 10	< 10
KCL	%	5	
Chloride	mg/l	>100,000	>180,000
MBT	lb/bbl.	< 5	< 5
LGS	%	< 5	< 5
pH		9.5 – 10.5	9.5 – 11
Sand	%	< 1	< 1

3.2 Calculations

This research deals with investigating the impact of using MPD on the ROP and mud Rheology, mud solids content and NPT. It was found that ROP could be impacted by some parameters including, mud weight pressure difference, Weight on bit formation Drill ability rotation rate (RPM), and delivery capacity.

3.2.1 MPD impact on ROP

Bourgoyne equation was used to estimate the ROP when MPD technique is used.

EQUATION was applied on five wells focusing on 12 ¼" and 8 ½" intervals.. The main input of this equation are the actual ROP and Mud weight which were used in conventional drilling. The other input was the depth for each meter while drilling and the Bourgoyne constant, which is, depend on several parameters effected on the rate of penetration such as WOB, RPM Mud density as mentioned in previous chapter.

$$ROP_2 = ROP_1\, e^{cD(MW_1 - MW_2)}$$

Where :

ROP_1	Rate of penetration (ft/m)
ROP_2	Rate of penetration (ft/m)
C	Constant based on bit type, formation and WOB or slope of shale line.
D	True vertical depth
MW_1	Mud weight at ROP_1 (ppg)
MW_2	Mud weight at ROP_2 (ppg)

3.2.2 MPD impact on Pressure Loss

The general input data (Drilling Parameters and Mud laboratory tests) for the software for all cases are shown below:

A. 12 ¼” Section

Table 9 Mud laboratory test & drilling parameters input of software (12 ¼” section)

Bit Depth	m	4500
Mud Pumps efficiency	%	96
Flow Rate	gal/min	800
ROP	m/hr.	5
RPM	rpm	80
Max. Pump pressure	psi	5000
Pump Pop-off Pressure	psi	4500
Surface Line ID	in	5
Surface Line Length	m	15.24
Bit nozzles		6*12
TFA	in^2	1.64

Mud Properties (LAB Test)	Unit	Without MPD	With MPD
Mud Weight	ppg	13.5	10
PV	cP	54	16
YP	lbs./100 ft^2	30	24
LSYP	lbs./100 ft^2	15	12
API / HTHP F/L	ml/30 min	5	3
pH		10	10
GEL Strength	lbs./100 ft^2	9	7
water/solids %	%	70/30	88/12
Cake Thickness API	32nd in	1	1
Salinity	wt.%	15	15

B. 8 ½” Section

Table 10 - Mud laboratory test & drilling parameters input of software (8 ½” section)

Bit Depth	m	4500
Mud Pumps efficiency	%	96
Flow Rate	gal/min	550
ROP	m/hr.	5
RPM	rpm	80
Max. Pump pressure	psi	5500
Pump Pop-off Pressure	psi	4500
Surface Line ID	in	5
Surface Line Length	m	15.24
Bit nozzles		6*14
TFA	in^2	1.53

Mud Properties (LAB Test)	Unit	Without MPD	With MPD
Mud Weight	ppg	14.5	10
PV	cP	74	16
YP	lbs./100 ft^2	35	24
LSYP	lbs./100 ft^2	17	12
API / HTHP F/L	ml/30 min	5	3
pH		10	10
GEL Strength	lbs./100 ft^2	9	7
water/solids %	%	64/36	88/12
Cake Thickness API	32nd in	1	1
Salinity	wt.%	15	15

3.2.3 MPD impact on Drilling Time

The other part of the calculation covered the impact of using MPD on drilling time. The result from the previous section, which is, ROP calculation was used as a base for calculating the drilling time saved by using managed pressure system technique. Furthermore the saving in drilling time will be later quantify the cost reduction in both cases the use of MPD and conventional drilling.

3.2.4 MPD impact on Drilling cost

The last part of this chapter will deal with economic of using MPD and impacted in drilling cost. More ever. the reduction of drilling time from using MPD will be considered in this section to estimate the saving in drilling cost.

CHAPTER 4 – Results and Discussion

The acquired data from five wells was used to in this study to investigate MPD impact on Drilling parameters. In this chapter, MPD effect on ROP, Pressure Loss, NPT and cost are presented as follow:

4.1 MPD impact on ROP

As mentioned in the previous chapter, the impact on ROP was investigated in two main sections in the five wells (12 ¼" and 8 ½"). The impact on these sections is shown below:

- **Well X1**

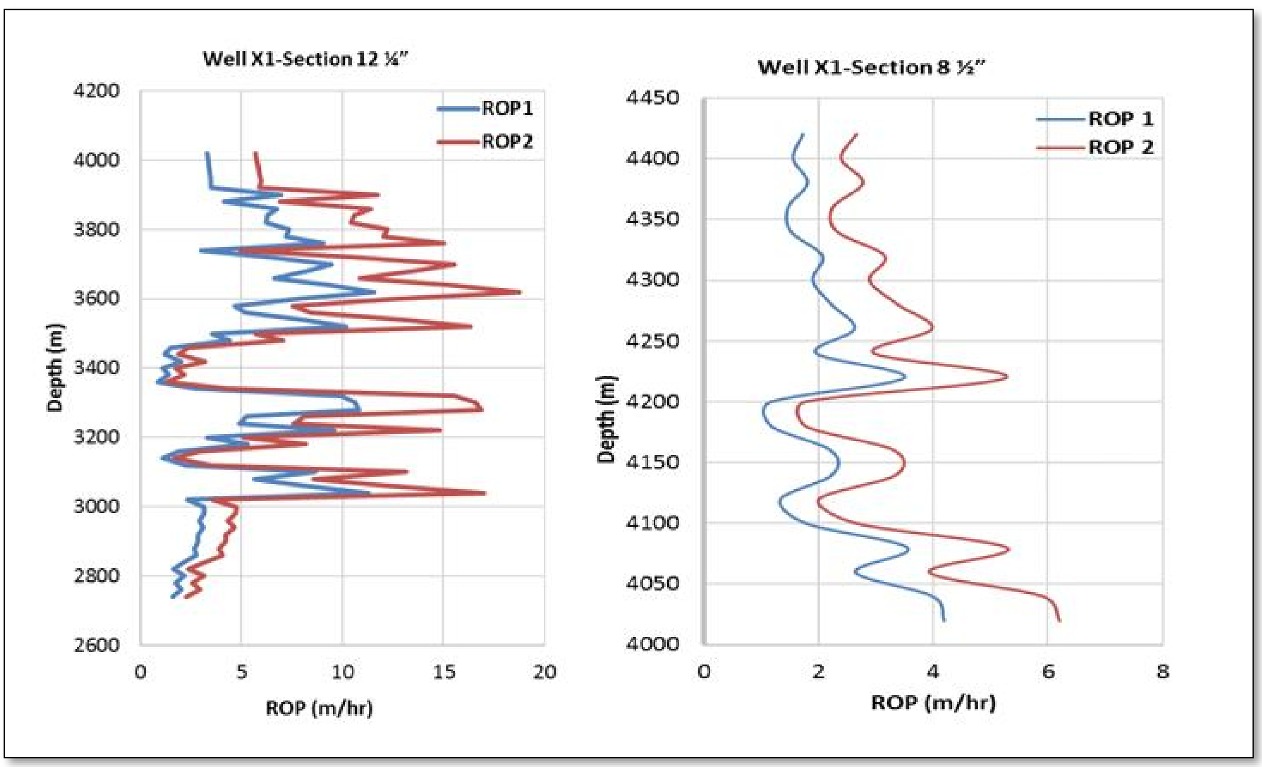

Figure 15- Increment of ROP in 12 ¼" and 8 ½" WELL X1

The Calculation that was done in Well X1 - Section 12 ¼" depicts that the ROP increased by 37 % with the use of managed pressure drilling system, while the increase was 34 % in 8 ½" section.

The above figure shows a consistent increase in the entire section. The increment in the ROP is attributed to the reduction in the pressure variation between the wellbore and the formation. This well shows the highest ROP increase compared with the other wells because it was an exploration well and the used mud weight was quite high. As a result, the impact of MPD was enlarged in this case because the increase in the mud weight will result in high overbalanced drilling pressure (Ph >>Pf).

- **Well X2**

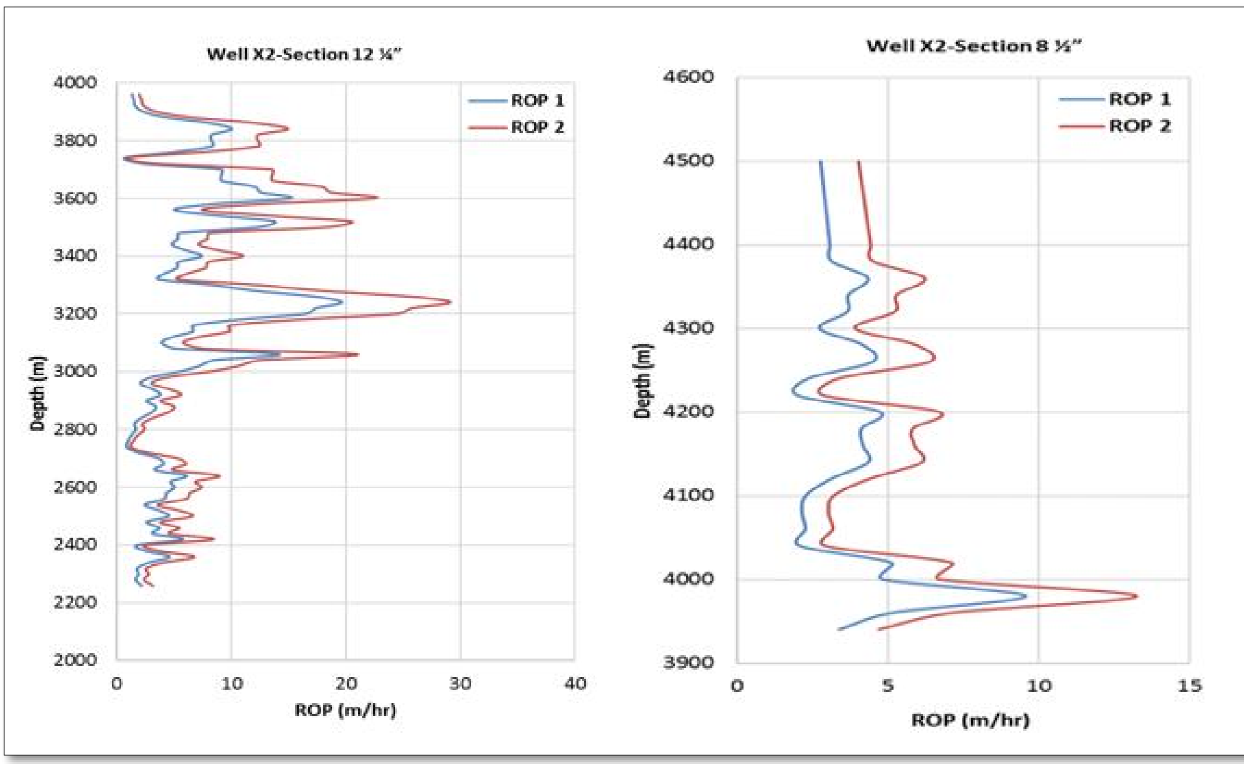

Figure 16 - Increment of ROP in 12 ¼" and 8 ½" WELL X2

The results from the case of Well X2– Section 12 ¼" shows that the ROP increased by 32% with the use of managed pressure drilling system technique, while the increase was 29 % in 8 ½" section. In this case, the improvement in the ROP was not as high as the case of Well X1. This is because Well X2 is the second drilled well in this filed and previous information was available and this is why the mud weight was not as high compared with the first case.

➢ **Well X3**

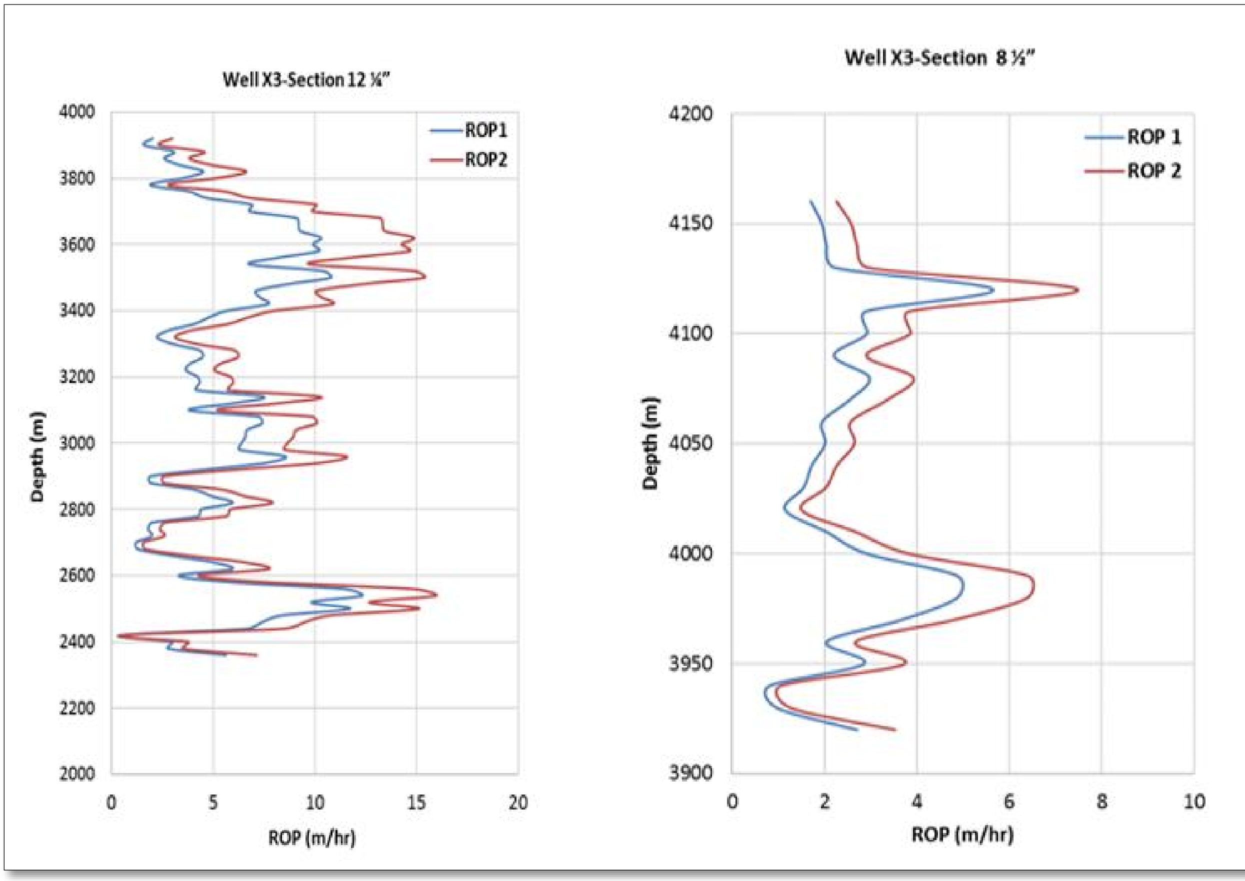

Figure 17 - Increment of ROP in 12 ¼" and 8 ½" WELL X3

The calculation that was done in Well X3 – Section 12 ¼" depicts that the ROP increased by 32% with the use of managed pressure drilling system, while the increase was 29 % in 8 ½" section. The above figure shows a consistent increase in the entire section. The increment in the ROP is attributed to the reduction in the mud weight used while drilling to reduce the pressure on the formation and moderate the RPM and increasing the Weight on bit (WOB) from (10 – 12) Ton. Because the Weight on bit is an essential factor in the drilling process. This well shows the significantly high ROP which well reducing the drilling time. As a result, the impact of MPD was clear in this case because the increase in the mud weight will result in high overbalanced drilling pressure.

- **Well X4**

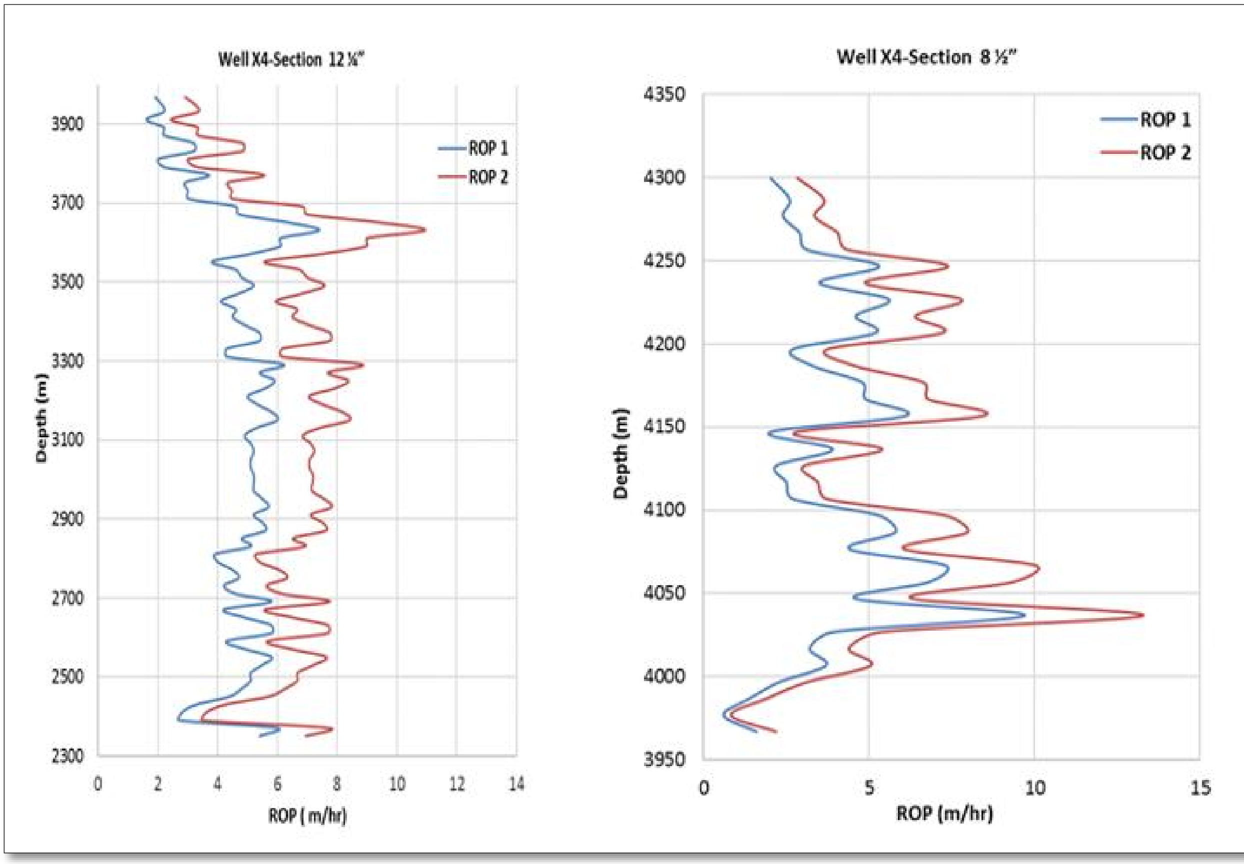

Figure 18 - Increment of ROP in 12 ¼" and 8 ½" WELL X4

The calculation that was done in Well X4 – Section 12 ¼" depicts that the ROP increased by 32% with the use of managed pressure drilling system, while the increase was 27 % in 8 ½" section. The above figure shows a consistent increase in the entire section. The increment in the ROP is attributed to the reduction in the mud weight used while drilling to reduce the pressure on the formation and moderate the RPM and increasing the Weight on bit (WOB) from (10 – 12) Ton. In the soft formation and use low WOB (3-5) Ton and high RPM while drilling the hard formation, because the Weight on bit is an essential factor in the drilling process.

➢ Well X5

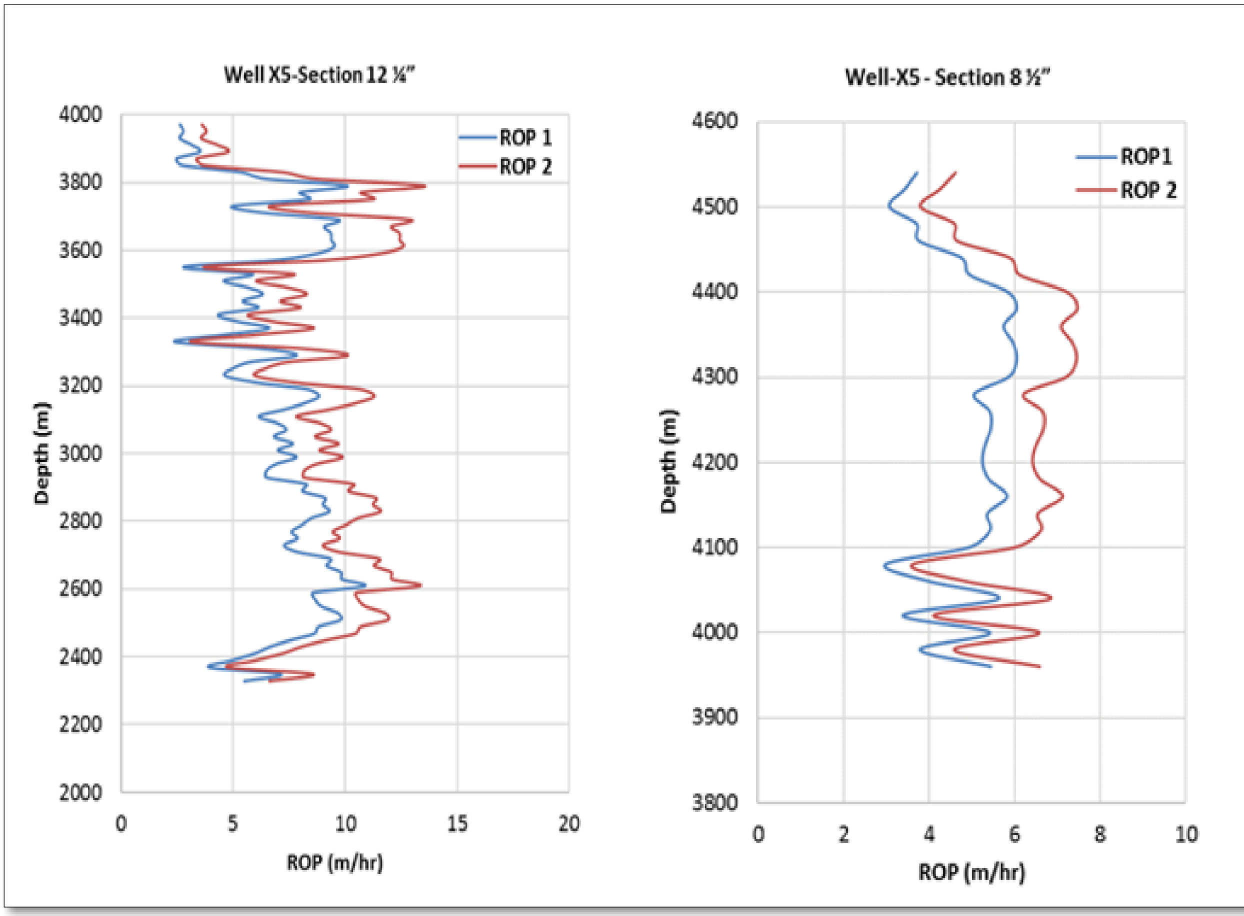

Figure 19 - Increment of ROP in 12 ¼" and 8 ½" WELL X5

Similar to the previous cases, the ROP was found in Well X5 to be increasing by 21% in 12 ¼" section and 18% in 8 ½" section. This case shows a lower increase in the ROP compared with the previous cases even though the optimum drilling parameters were used in this well. This is attributed to the formation compaction as the drilled rocks were more compact in this well and that resulted in lower increase in the ROP.

4.2 MPD impact on pressure loss

4.2.1 Case.1 Conventional drilling (12 ¼" interval)

For simulation, runs were done by using hydraulic pressure simulator based on the drilling parameters and mud laboratory tests properties mentioned in previous chapter. The result of the simulation runs is listed below for each case.

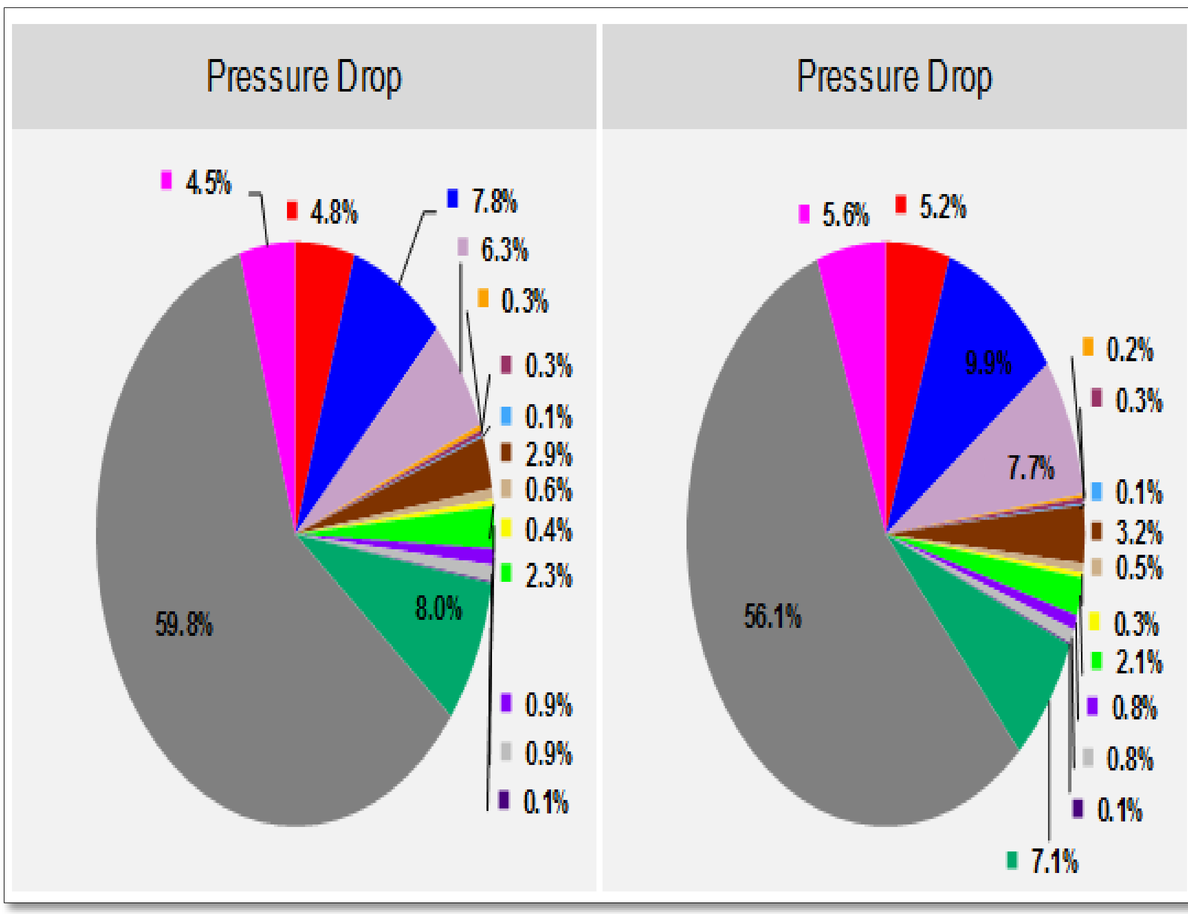

Figure 20 - Pressure drop distribution 12 ¼" BHA

The above result by simulator for pressure drop indicated the high-pressure drop is happening in the drill pipe in both cases. However, the pressure drops in the drill string. When managed pressure system techniques are used was found to be lesser compared with the pressure drop of conventional drilling. Total pressure loss in MPD case was 3139.74 psi while in the conventional drilling was4627 psi.

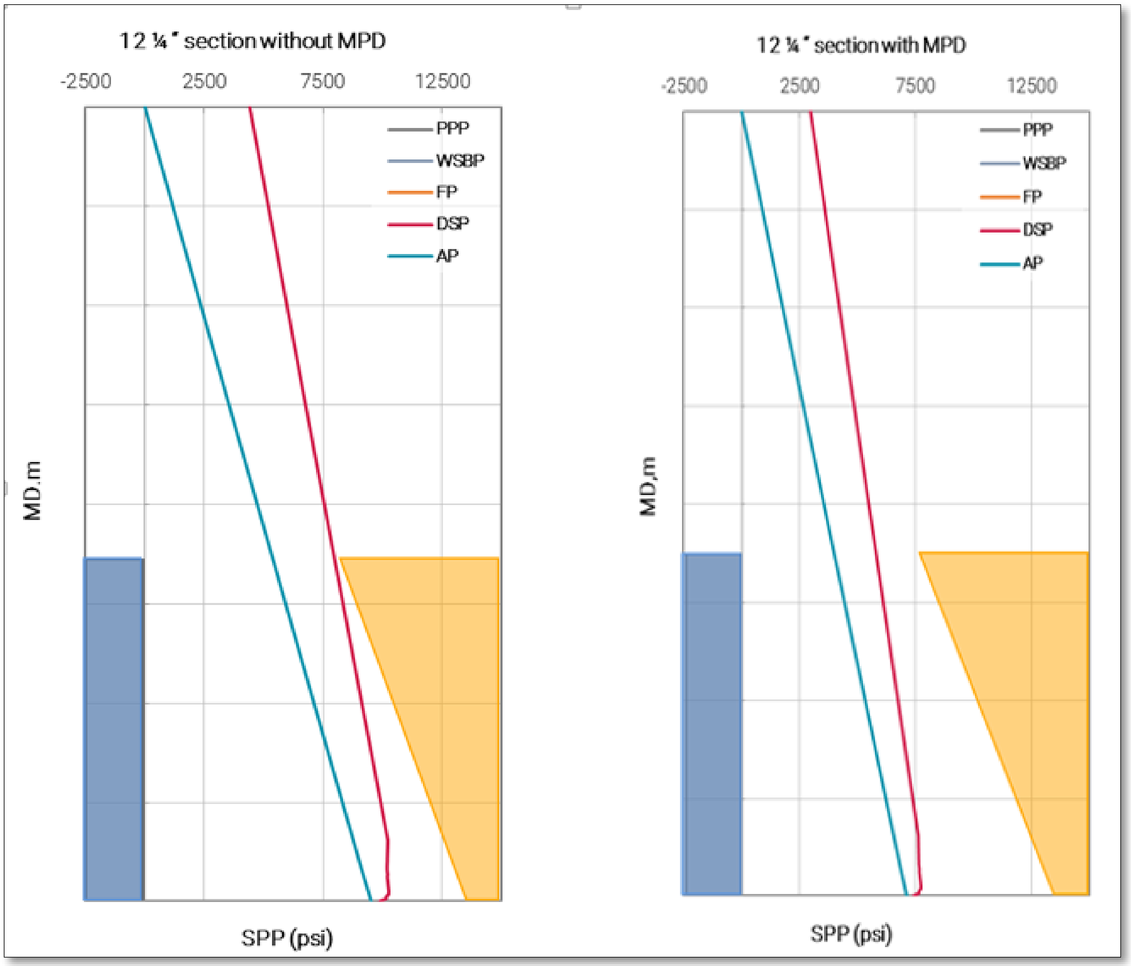

Figure 21 - Standpipe pressure distribution through wellbore 12 ¼" section

Also, the above charts show that the stand pipe pressure while drilling was lower in MPD case and it was far away from the fracture pressure consequently, the use of MPD enhances the drilling process with more safe condition as we stay away from fracking the formation. Moreover, lowering the pressure applied on the wellbore will minimize mud invasion into the formation. Resulting in less damage that might affect the production later also will reduce the cost of stimulation.

4.2.2 Case.2 Drilling with MPD (8 ½" interval)

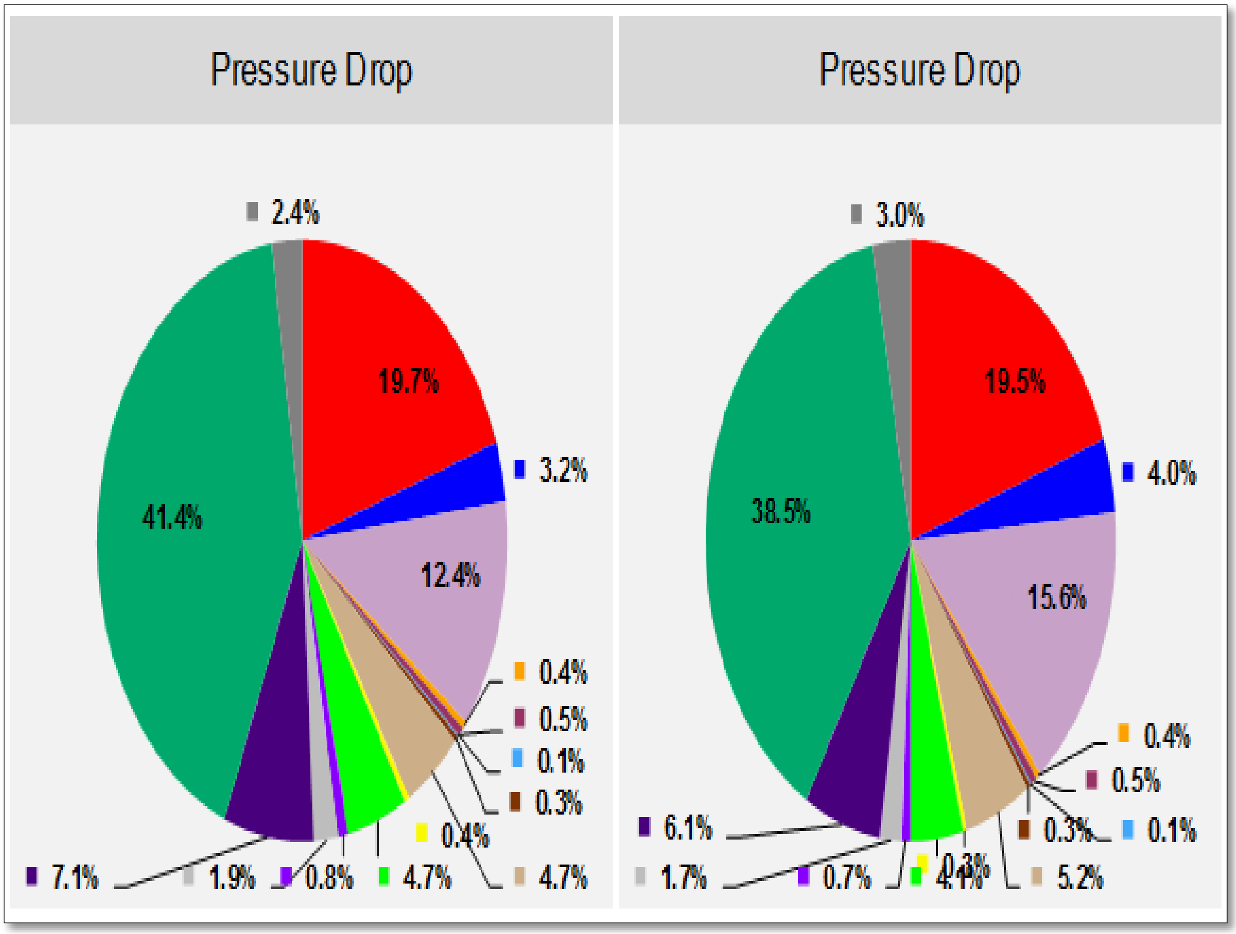

Figure 22 - Pressure drop distribution 8 ½" BHA

Similar to the 12 ¼" section, simulation runs show that the highest pressure drop occurs in the drill pipe. The manage pressure system technique minimized the pressure drop in the standpipe pressure as in the 12 ¼" section case. However, in the 8 ½" section case the percentage of pressure drop in the standpipe is less than the pressure drops in the standpipe within the 12 ¼" section case. This is attributed to the flow rate limitation in this section, as the area of the section is smaller as well as having smaller size of mud motors and bit nozzles.

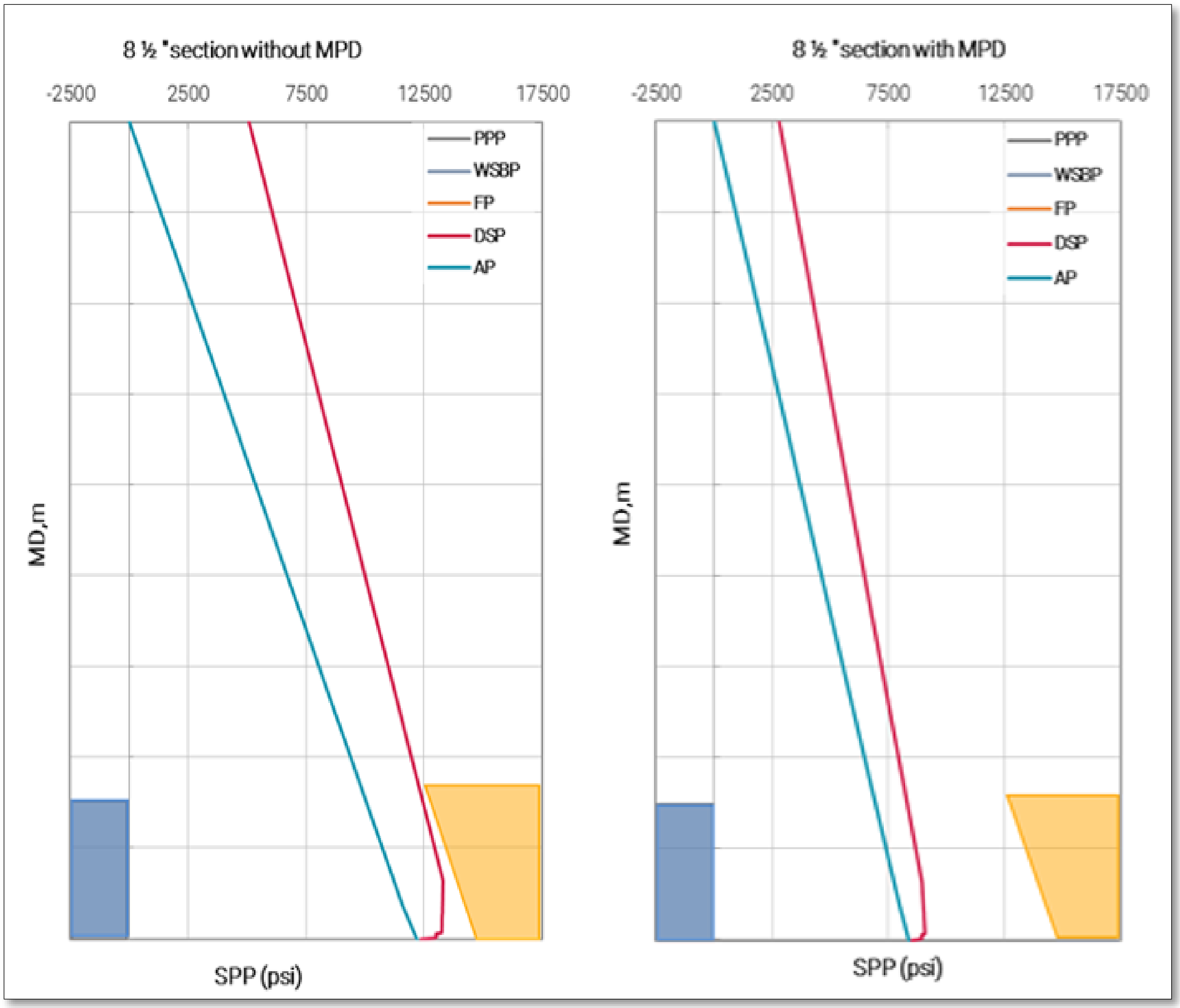

Figure 23 - Standpipe pressure distribution through wellbore 8 ½" section

Similar to 12 ¼" section, the software shows the distribution of Stand pipe pressure while drilling operation among 8 ½" section, that the SPP is reduced enough to be far away from the fracture pressure and enhanced the safety of drilling without fracking the formation while drilling and reducing the affection of equivalent circulation density specially with small section. The result supporting the previous distribution of stand pipe pressure with 12 ¼" section.

4.3 MPD Impact on Drilling Time

This study proves that the use of MPD technique provides a significant saving in terms of drilling time compared with the conventional drilling. The time of drilling both 12 ¼” and 8 ½” sections in 5 wells was analyzed and the results are shown below:

1. Time Save in 12 ¼” Section

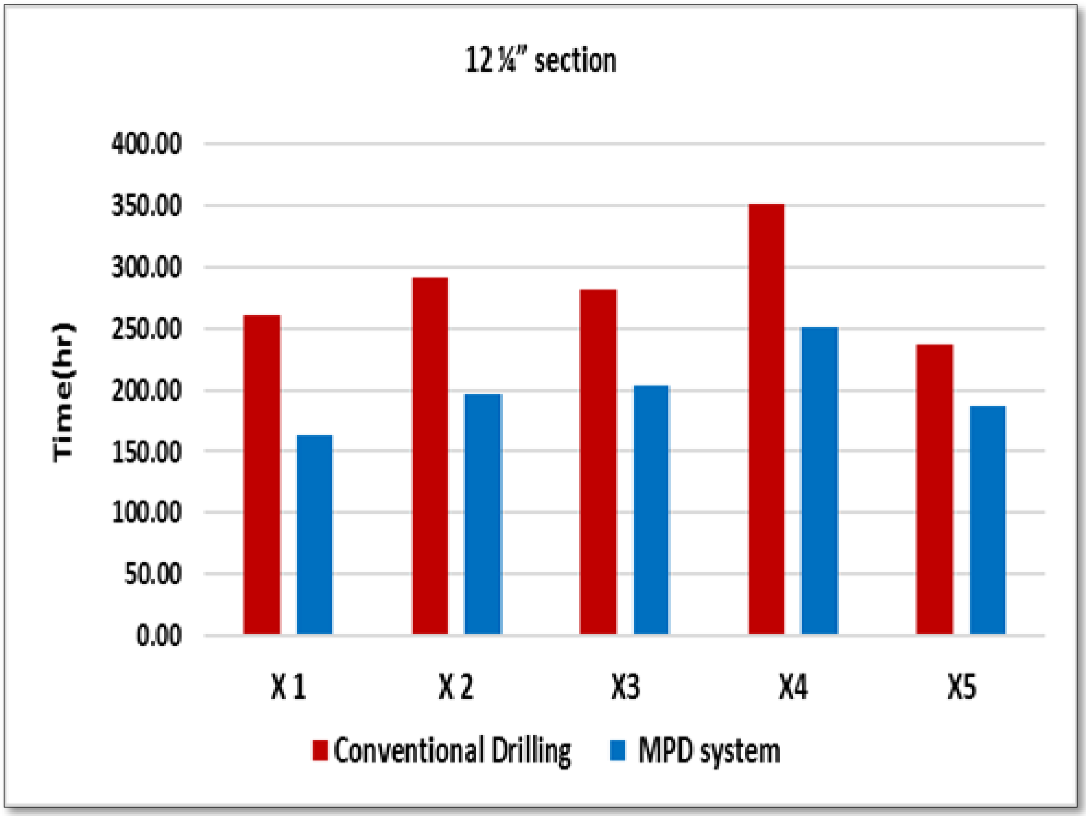

Figure 24 - Drilling time optimization 12 ¼” Section

The total time save in drilling the 12 ¼” section in the 5 wells was estimated to be 30%. The highest times saved was in well X4 and it was calculated to be 250 hours instead of 350 hours. Figure 21 shows times saving in 12 ¼” section for 5 wells drilled.

2. Time Save in 8 ½" Section

The use of MPD system in these five wells in 8 ½" sections was found to reduce the required time to drilling compared with the case of conventional drilling. From figure 22, MPD system helped to save up to 27 % of the required time when the conventional drilling was used.

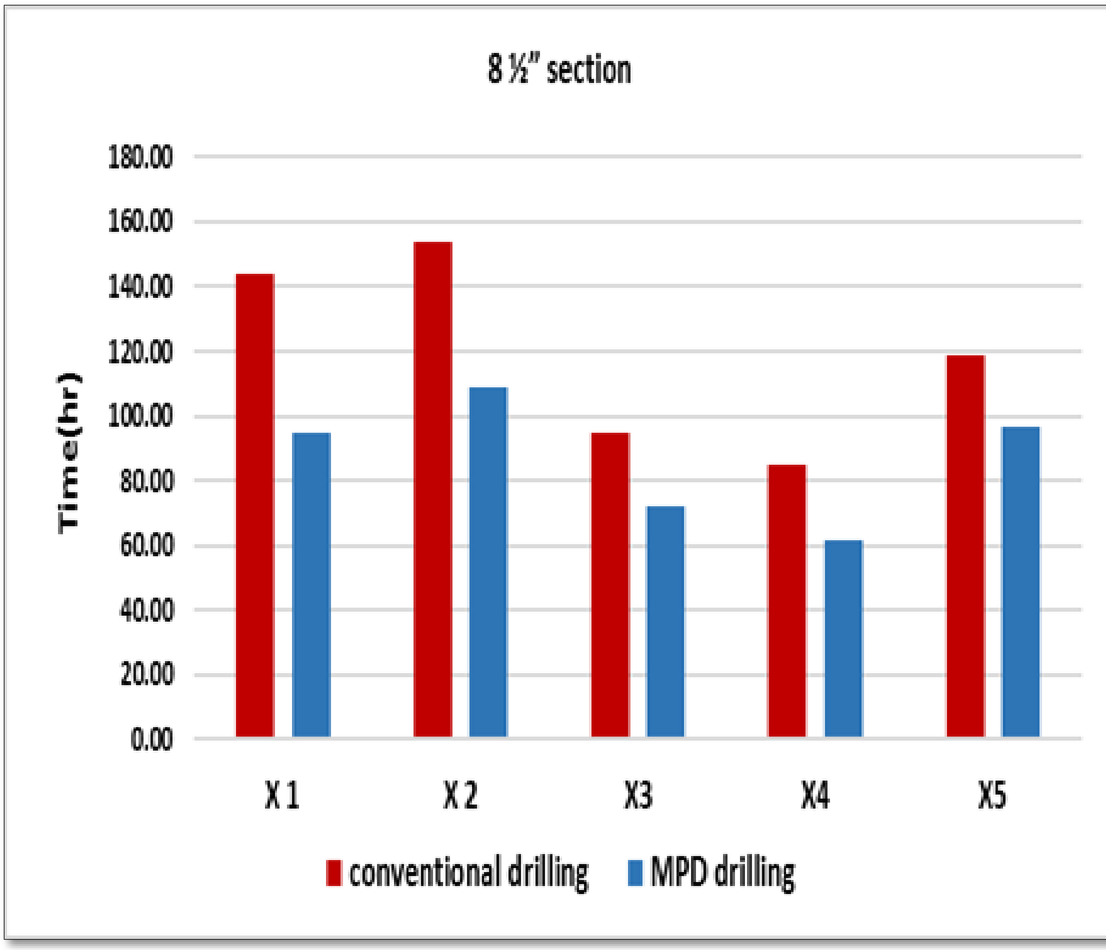

Figure 25 - Drilling time optimization 8 ½" Section

4.4 Cost Reduction by Using MPD

This research demonstrates that the use of MPD system can lower the cost of drilling the studied sections in the fives drilled wells in this field. The cost saved was mainly by lowering the drilling time, which reduces rig cost, as well as reduced the density of the required drilling fluids.

1. Cost Reduction in **12 ¼" Section**

By comparing the total cost in the conventional drilling case and the case of using MPD system in 12 ¼" section, it was found that the required cost to drill this section in all five wells could be reduced by 27 %. The main cost reduction in this section was achieved by lowering the required drilling time, which resulted in minimizing the Rig cost. Minimizing the required time help to lower staff cost and led in significant cost saving in the entire project.

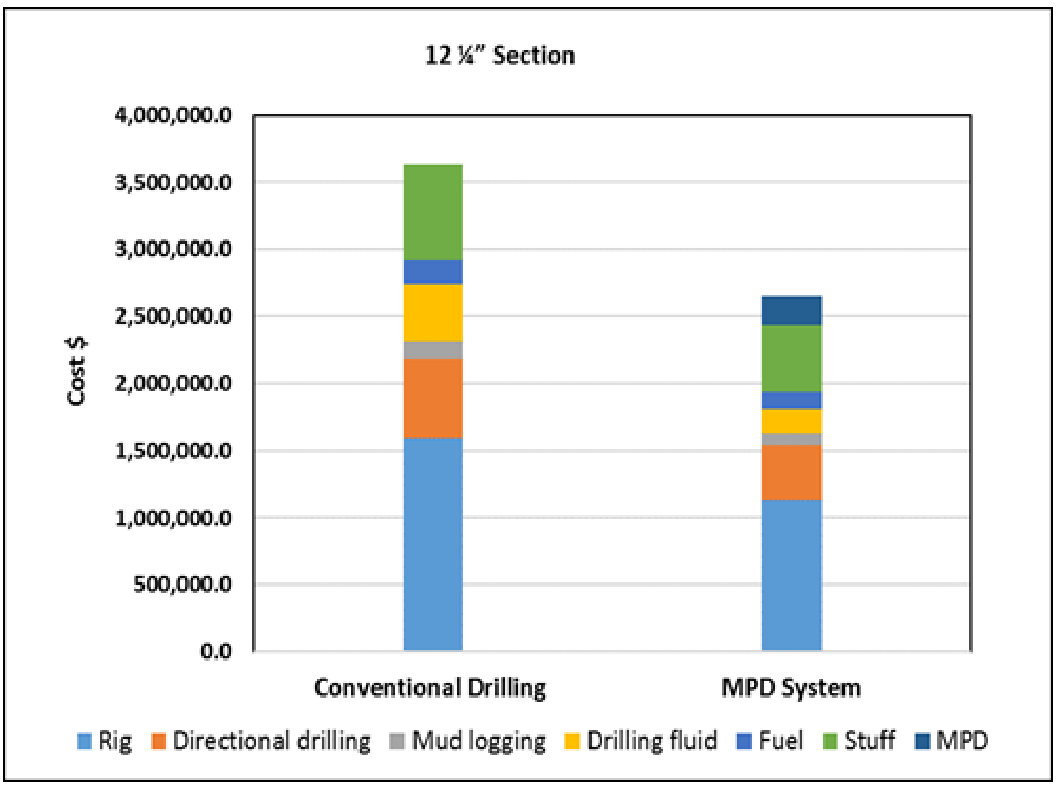

Figure 26 - Drilling cost optimization 12 ¼" Section

2. Cost Reduction in 8 ½" Section

Similar to the 12 ¼" section, using MPD cut about 25 % of the total cost in the 8 ½" section in the five drilled wells. However, the key cost saving in this section was in the drilling fluid due to the high variation in the mud weight used in the conventional drilling and MPD system.

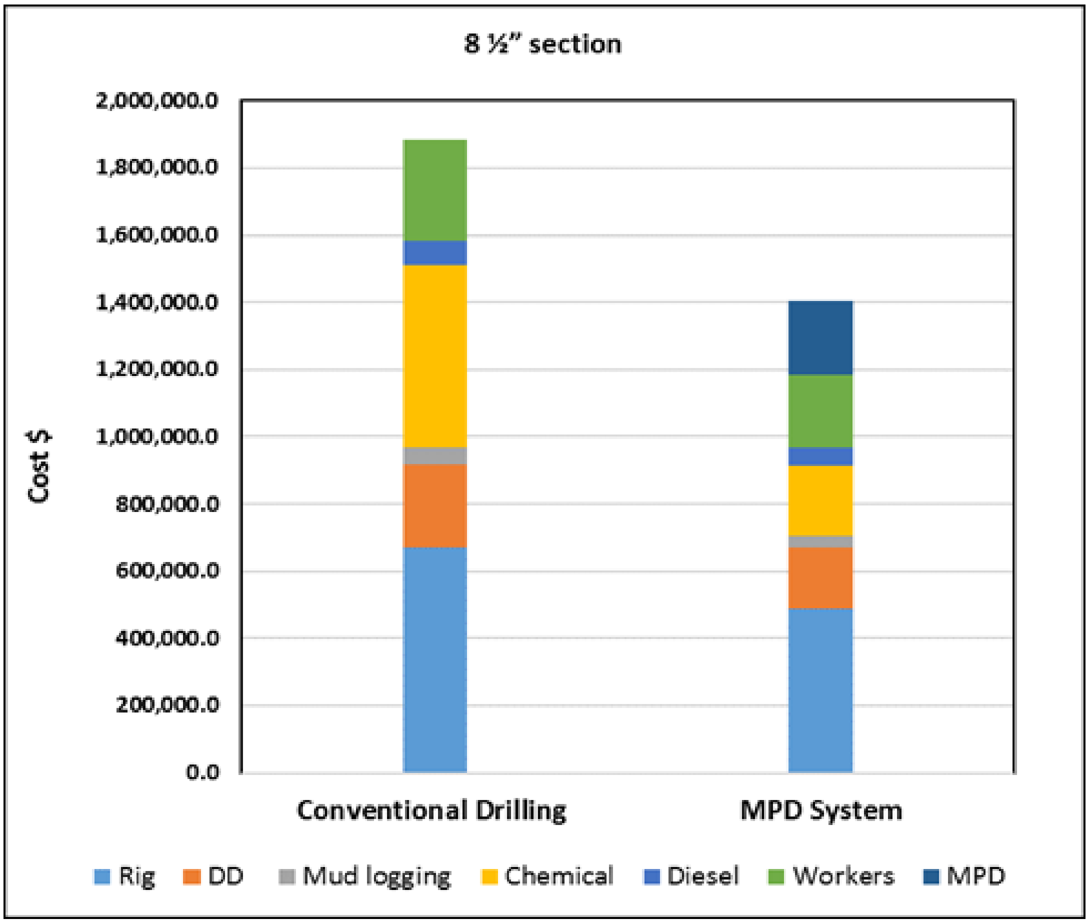

Figure 27 - Drilling cost optimization 8 ½" Section

CHAPTER 5 – Conclusion

The purpose of this research was to investigate the benefit of using managed pressure drilling technique (MPD) and whether it would provide a noticeable feasibility during drilling process. Two different case were considered in this research including the conventional drilling process and the drilling process by the use of MPD. In this research, two main intervals (12 ¼" & 8 ½") were investigated under the effect of MPD system, and both of these intervals included production zones. After studying and analyzing the results from the previous chapter, the findings of this research can be proposed as follows:

1. The rate of penetration is obviously increased by applying the MPD due to the reduction in the mud density, which leads to lower the overbalance pressure on the drilled rock.

2. After investigating the ROP increments with MPD system. It was found the drilling parameters such as WOB, RPM and bit selection, etc., have additional impact on the ROP increment.

3. With the use of MPD, pressure losses are reduced due to the reduction in mud weight, solids content and mud rheology. These factors were distinguished to be helpful for drillers to increase the pump rate and to enhance hole cleaning which will lead to avoid the drilling problems such as mechanical stuck.

4. The enhancement of drilling time reduction was clear in all the five wells during MPD application. Consequently, the NPT, and the hazards of drilling operations were minimized.

5. The time saved by using MPD system will have a huge impact on reducing the cost of drilling these wells as well as lowering the associated potential risks and environmental hazard during drilling process.

6. ROP calculations show the importance of Bourgoyne equation. Moreover, how this equation can predict the logic increment of ROP by using the optimum drilling parameters.

7. The use of MPD helps to enhance well production and minimizes the cost of stimulation due to the reduction in mud invasion and lowering the chances of blocking production pathways by inert drilling material such as Barite, which is used to control wellbore pressure.

8. The use of MPD system is very beneficial for drilling safety. The reduction in drilling time and the required mud weight provide an advantage that leads to quick detection of kick and losses while drilling.

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Appendix

Pressure drop distribution 12.25" interval with Conventional drilling

	Component	Distribution	P. Loss
		%	psi
●	Annulus	4.8	224.8
●	Bit	7.8	364.9
●	Hyper Line™ 250 Drill.	6.3	295.2
●	String Stabilizer	0.3	10.83
●	4 Drill Collar	0.3	13.12
●	Roller Reamer	0.1	1.21
●	MWD System	2.9	136.7
●	Non-Mag Drill Collar	0.6	24.94
●	8 1/4" PBL sub	0.4	14.67
●	Drill Collar	2.3	104.9
●	Dailey® Hydraulic Drill	0.9	38.12
●	Drill Collar	0.9	39.33
●	X-over	0.1	3.45
●	HWDP	8	375.9
●	G105 19.5# Drill Pipe	59.8	2861
●	Inlet Surface Equip.	4.5	209.9
	U Tube		-92.4
	SPP		**4627**

Pressure drop distribution 12.25" interval with MPD drilling

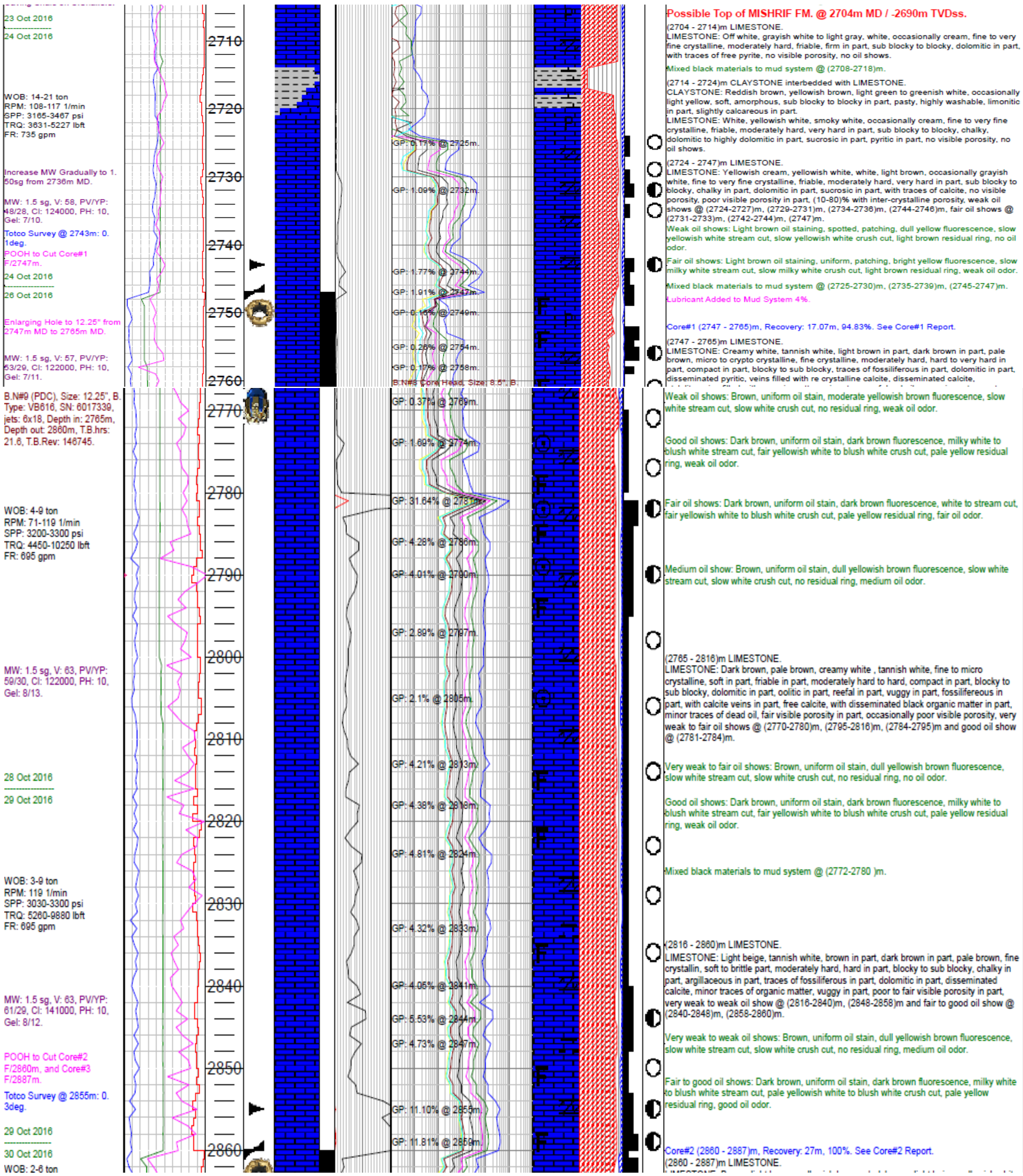
	Component	Distribution	P. Loss
		%	psi
●	Annulus	5.2	165.34
●	Bit	9.9	313.67
●	Hyper Line™ 250 Drill.	7.7	243.8
●	String Stabilizer	0.2	6.3
●	4 Drill Collar	0.3	8.11
●	Roller Reamer	0.1	0.7
●	MWD System	3.2	100.33
●	Non-Mag Drill Collar	0.5	14.97
●	8 1/4" PBL sub	0.3	8.65
●	Drill Collar	2.1	64.87
●	Dailey® Hydraulic Drill	0.8	22.49
●	Drill Collar	0.8	24.32
●	X-over	0.1	2.03
●	HWDP	7.1	225.56
●	G105 19.5# Drill Pipe	56.1	1814.49
●	Inlet Surface Equip.	5.6	176.76
	U Tube		-52.65
	SPP		**3139.74**

Pressure drop distribution 8.5" interval conventional drilling

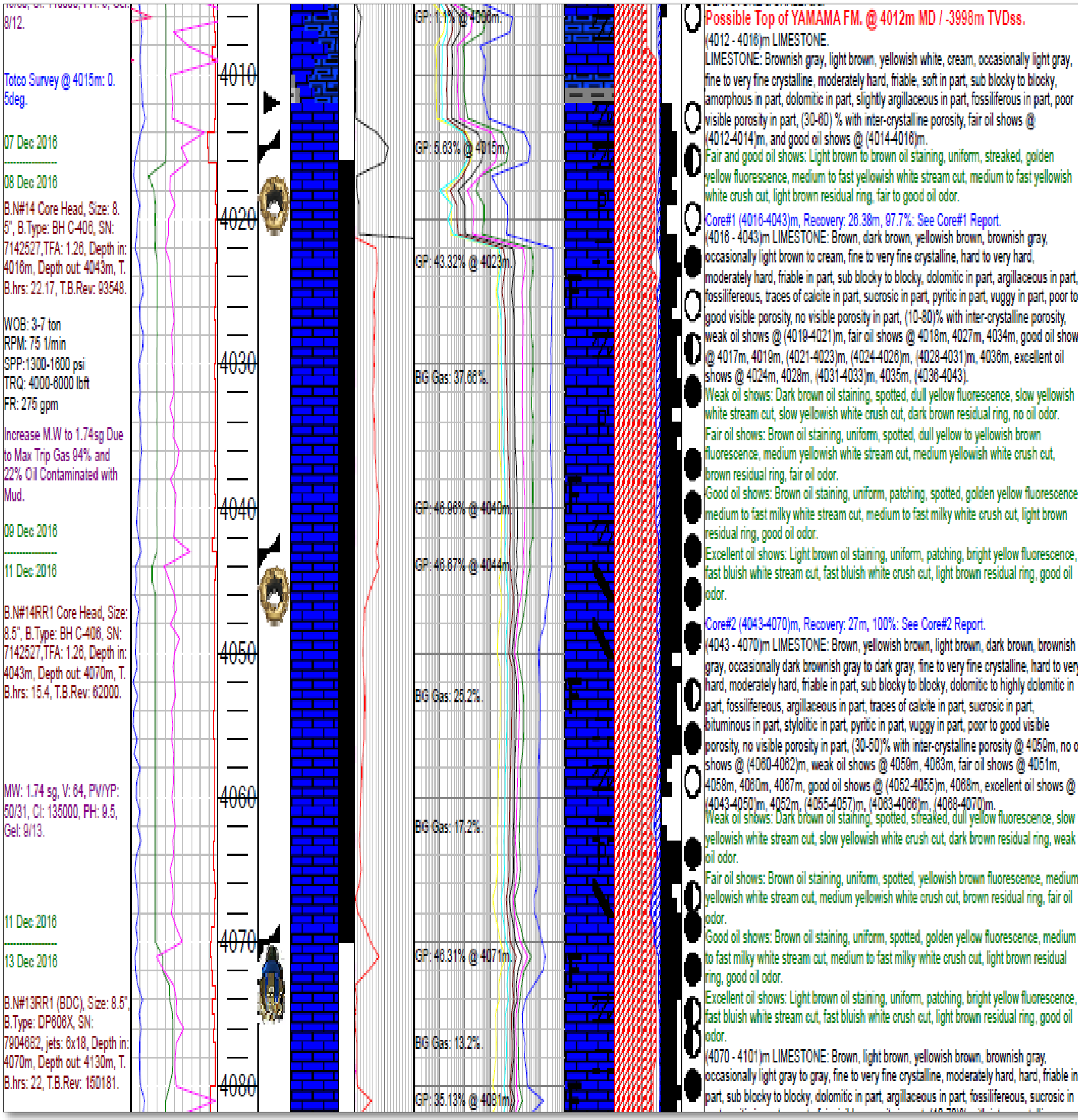
Component		Distribution	P. Loss
		%	psi
● (red)	Annulus	19.7	1042.59
● (blue)	Bit	3.2	168.2
● (light purple)	Hyper Line™ 250 Drill.	12.4	656.41
● (orange)	String Stabilizer	0.4	20.94
● (maroon)	Drill Collar	0.5	24.91
● (light blue)	Roller Reamer	0.1	1.81
● (brown)	Non-Mag Drill Collar	0.3	12.39
● (tan)	HEL™ MWD System	4.7	247.48
● (yellow)	6 3/4" PBL sub	0.4	16.54
● (green)	Drill Collar	4.7	249.07
● (violet)	Dailey® Hydraulic Drl.	0.8	39.4
● (light grey)	Drill Collar	1.9	99.6
● (dark purple)	HWDP	7.1	373.41
● (teal)	G105 19.5# Drill Pipe	41.4	2227.3
● (grey)	Inlet Surface Equip.	2.4	125.94
	U Tube		-101
	SPP		**5204.99**

Pressure drop distribution 8.5" interval drilling with MPD

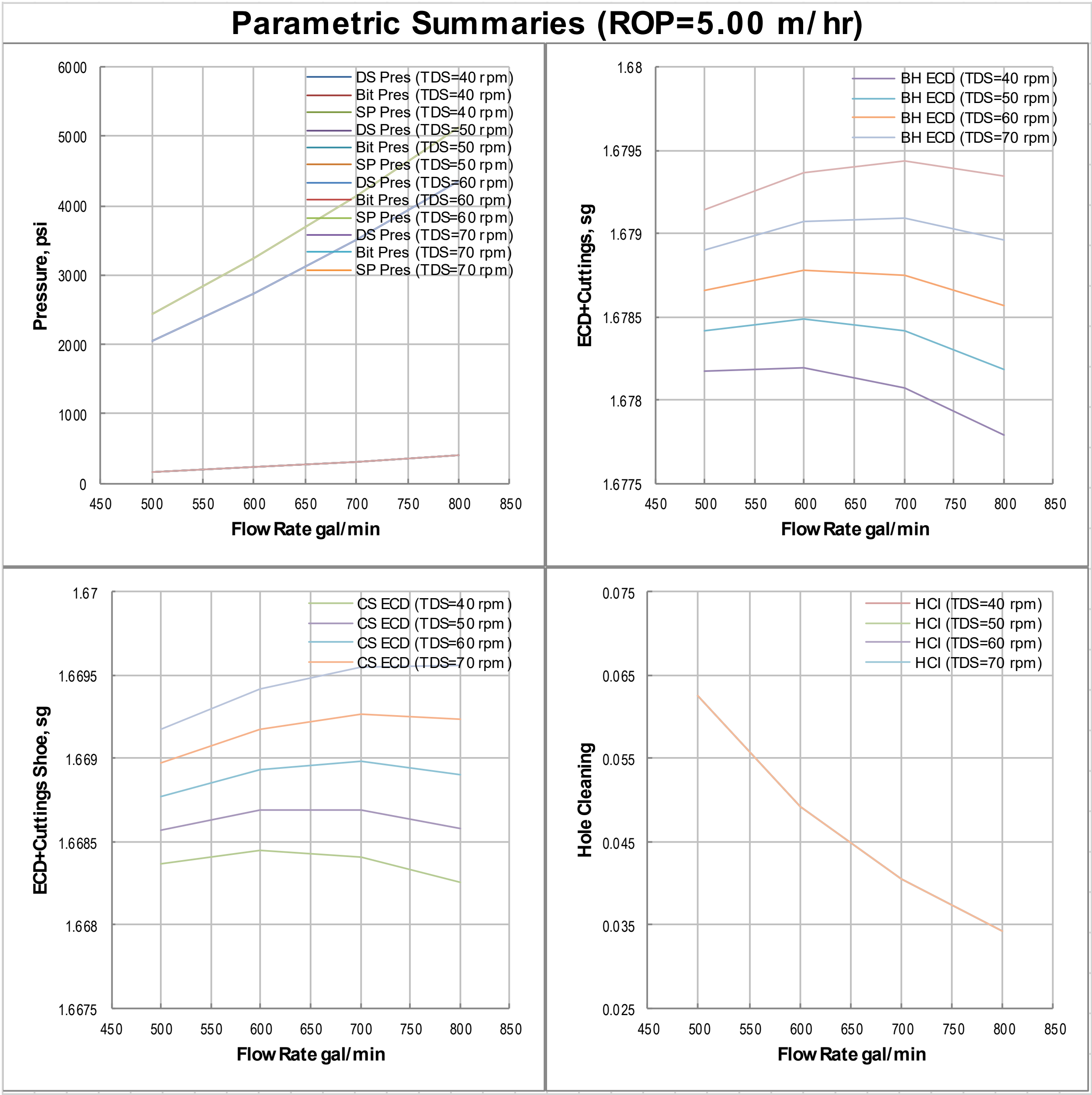
Component		Distribution	P. Loss
		%	psi
● (red)	Annulus	19.5	571.07
● (blue)	Bit	4	117.1
● (light purple)	Hyper Line™ 250 Drill.	15.6	457.66
● (orange)	String Stabilizer	0.4	9.26
● (maroon)	Drill Collar	0.5	11.84
● (light blue)	Roller Reamer	0.1	0.8
● (brown)	Non-Mag Drill Collar	0.3	6.13
● (tan)	HEL™ MWD System	5.2	152.66
● (yellow)	6 3/4" PBL sub	0.3	7.5
● (green)	Drill Collar	4.1	118.4
● (violet)	Dailey® Hydraulic Drl.	0.7	18.32
● (light grey)	Drill Collar	1.7	47.36
● (dark purple)	HWDP	6.1	177.56
● (teal)	G105 19.5# Drill Pipe	38.5	1159.7
● (grey)	Inlet Surface Equip.	3	88.01
	U Tube		-59.2
	SPP		**2884.17**



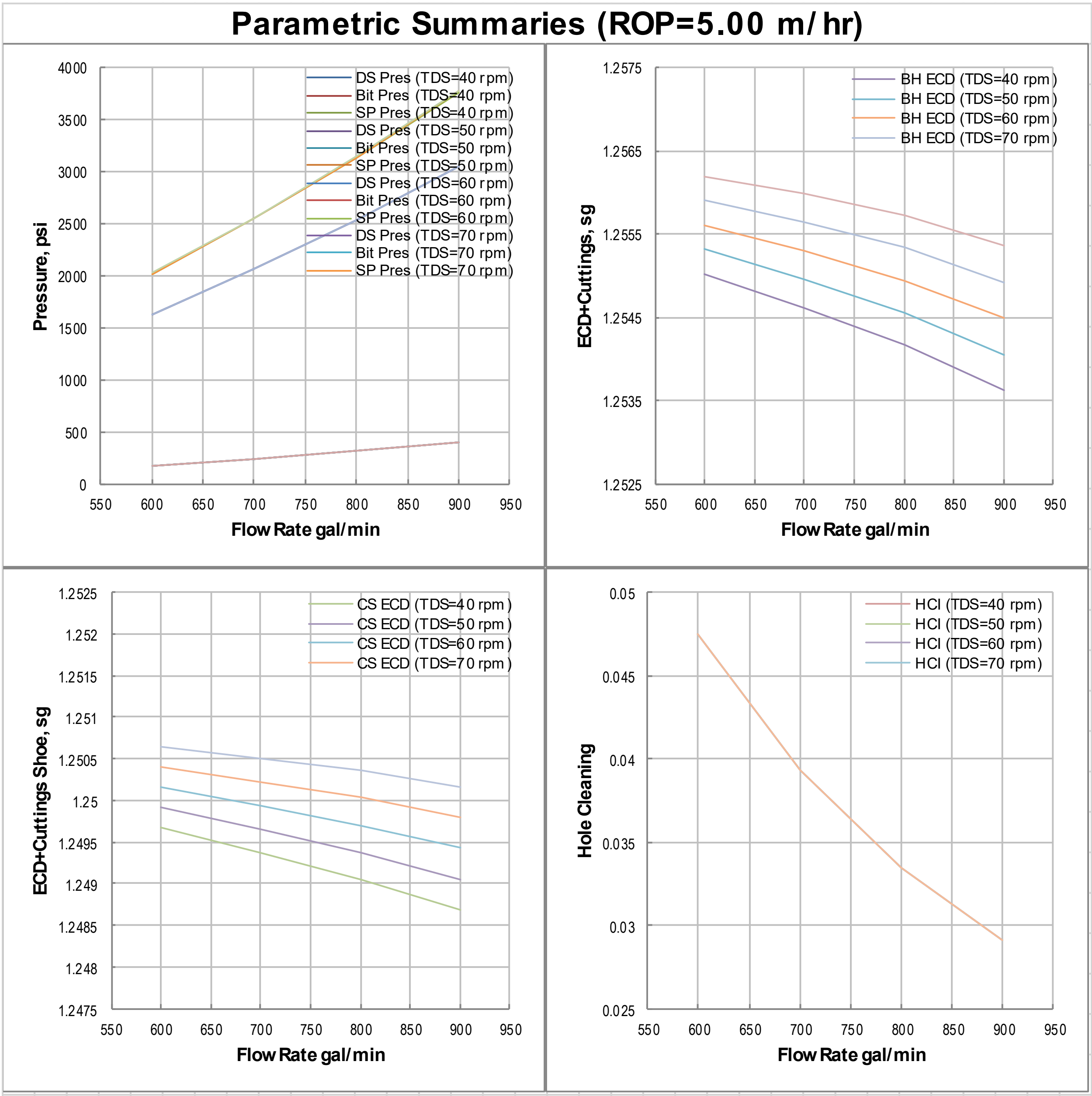
Master log description of reservoir Mishrif formation



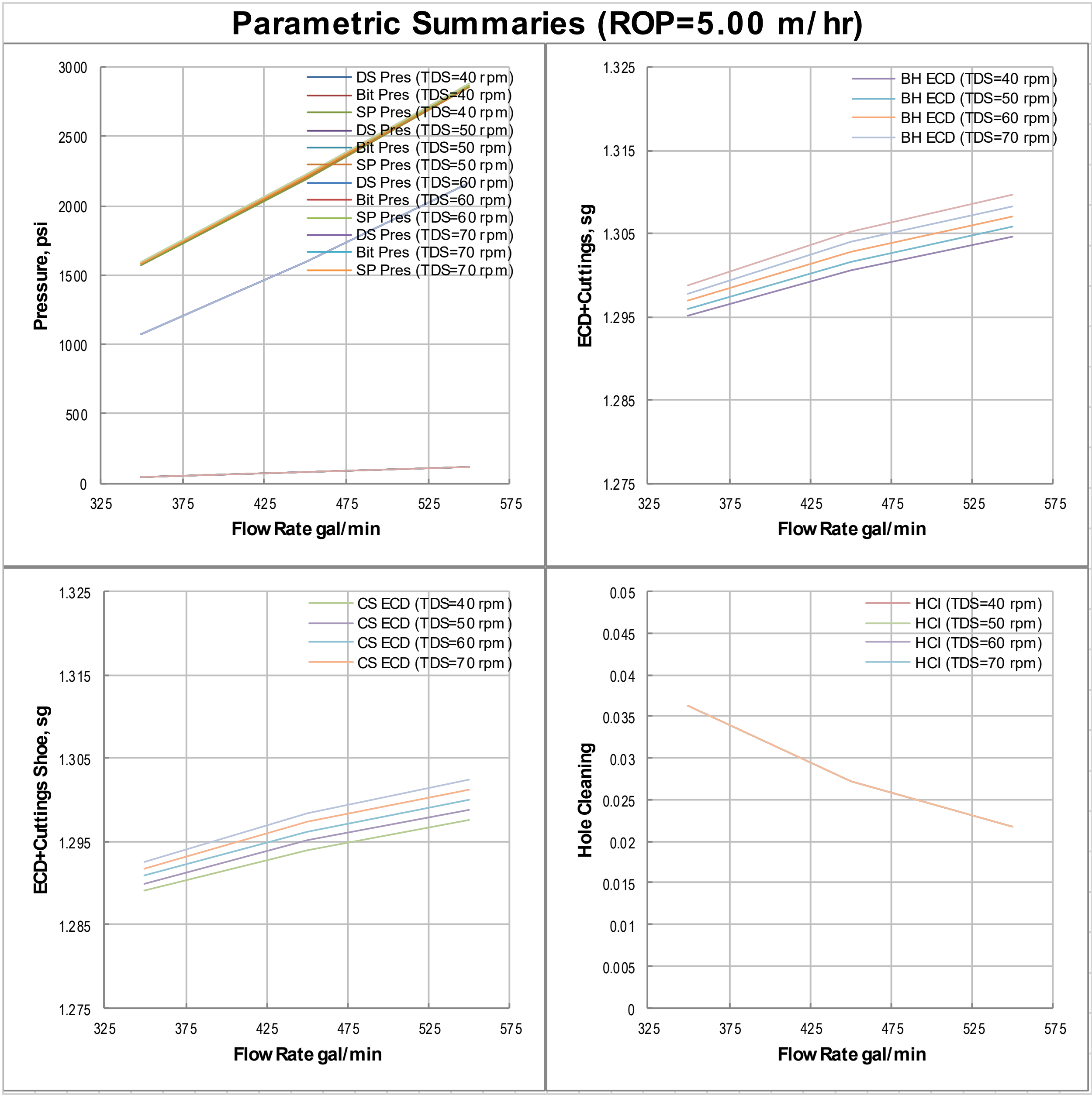
Master log description of reservoir Yamama formation



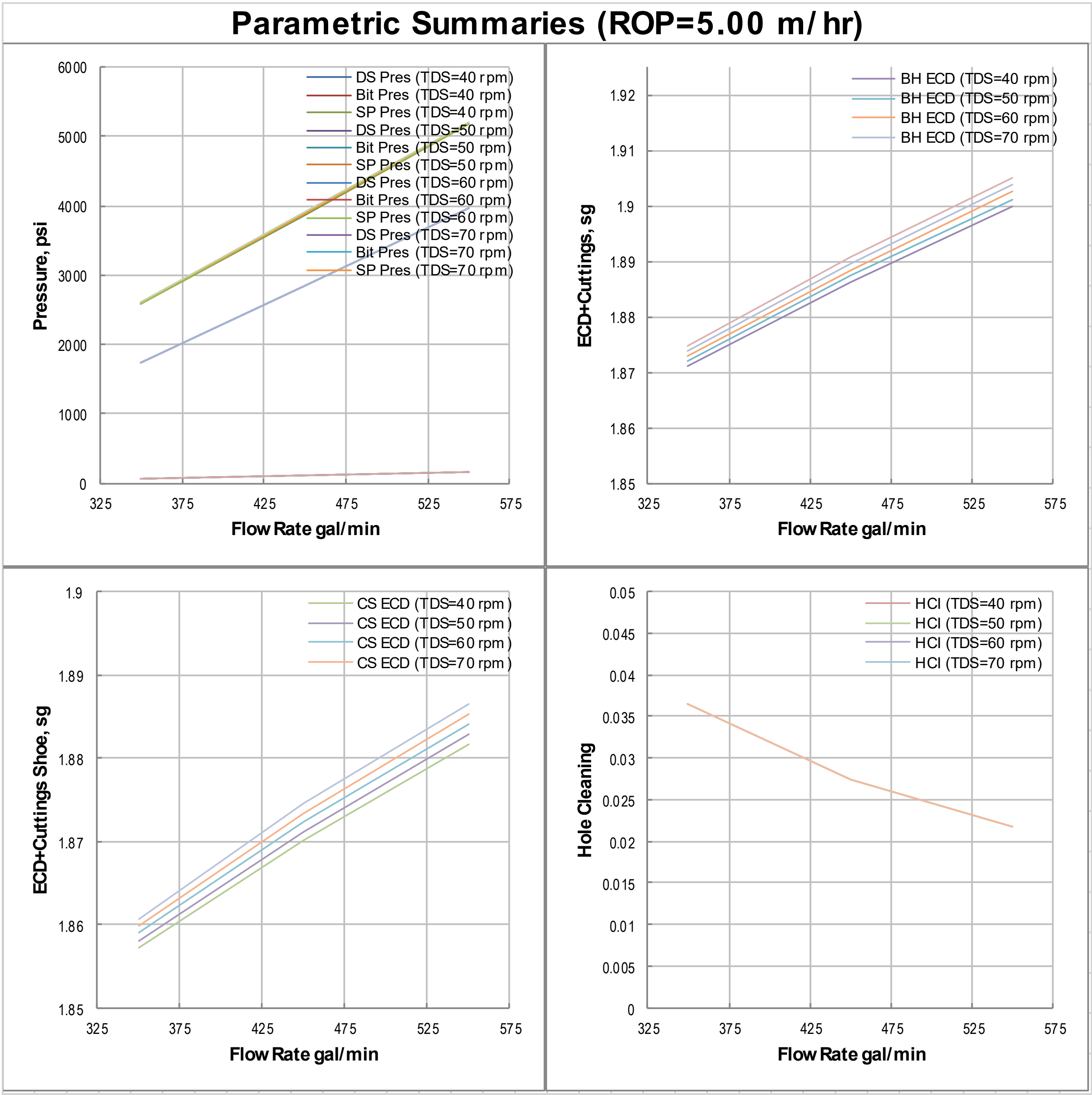
ECD Distribution 12 ¼" conventional drilling



ECD Distribution 12 ¼" MPD drilling



ECD Distribution 8 ½" MPD drilling



ECD Distribution 8 ½" conventional drilling

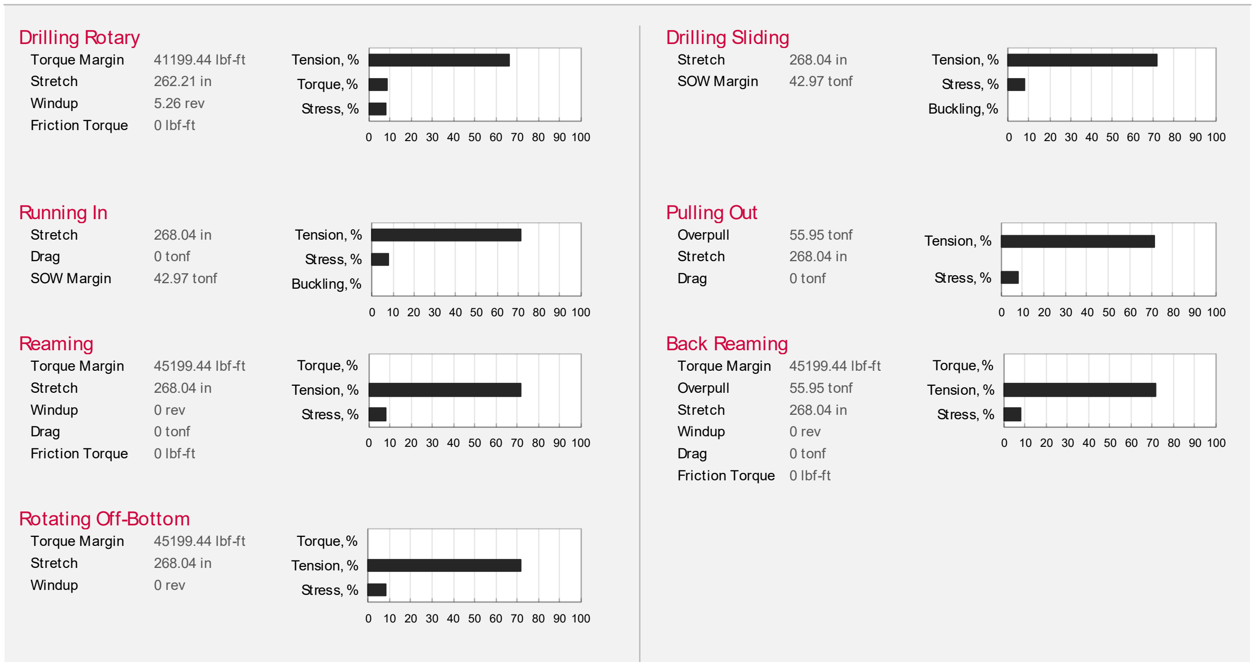
Analysis Settings

Well Depth, m	4506
Mud Weight, sg	1.2
Rig Hoisting Limit, tonf	30
Max Rig Torque, lbf-ft	35000
Rig Torque Setting, lbf-ft	28000

Operational Settings (Average Parameters)

Activity	WOB tonf	TOB lbf-ft	ROP/ Speed m/ hr	Surf. RPM rpm
Rotary	10	4000	5	80
Sliding	0		0	

Activity	ROP/ Speed m/ min	Surf. RPM rpm
Running In	10	
Pulling Out	10	
Rot Off Btm		80
Reaming	18.29	60
Back Reaming	18.29	60



Tension, stress and buckling while tripping in and out (8 ½" section)

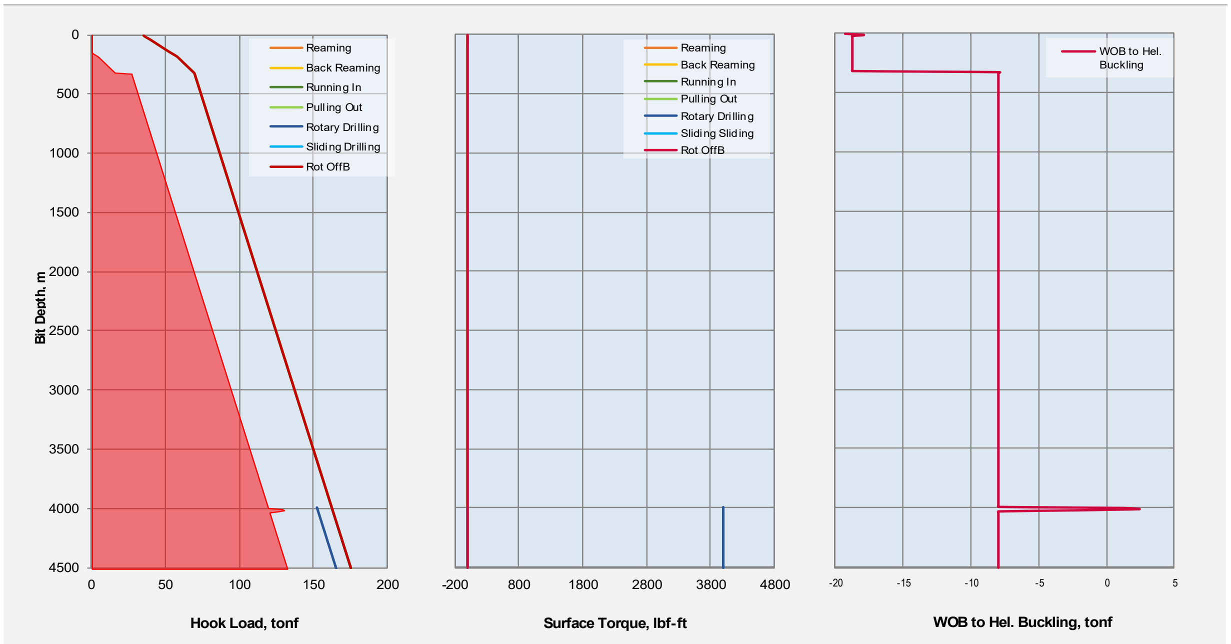
Analysis Settings

Well Depth, m	4506
Mud Weight, sg	1.2
Rig Hoisting Limit, tonf	30
Max Rig Torque, lbf-ft	35000
Rig Torque Setting, lbf-ft	28000

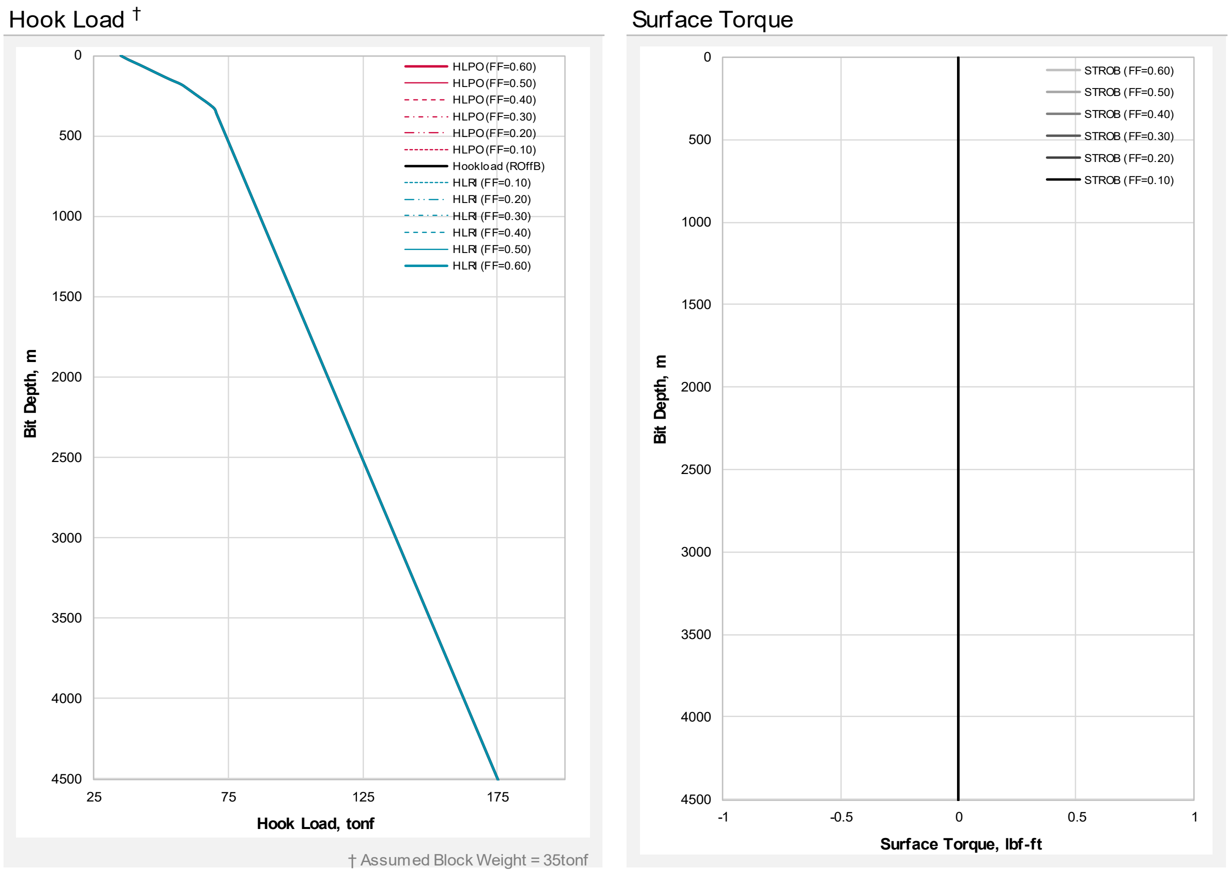
Operational Settings (Average Parameters)

Activity	WOB tonf	TOB lbf-ft	ROP m/hr	Surf. RPM rpm
Rotary	10	4000	5	80
Sliding	0		0	

Activity	RS m/min	Surf. RPM rpm
Running In	10	
Pulling Out	10	
Rot Off Btm		80
Reaming	18.29	60
Back Reaming	18.29	60



Hook load and surface torque distribution (8 ½" section)



Hook load and surface torque distribution while drilling process (8 ½” section)

Analysis Settings

Well Depth, m	3992
Mud Weight, sg	1.2
Rig Hoisting Limit, tonf	30
Max Rig Torque, lbf-ft	35000
Rig Torque Setting, lbf-ft	28000

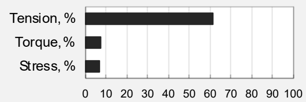
Operational Settings (Average Parameters)

Activity	WOB tonf	TOB lbf-ft	ROP/Speed m/hr	Surf. RPM rpm
Rotary	12	3500	5	80
Sliding	0		0	

Activity	ROP/Speed m/min	Surf. RPM rpm
Running In	10	
Pulling Out	10	
Rot Off Btm		80
Reaming	18.29	60
Back Reaming	18.29	60

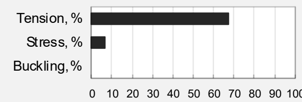
Drilling Rotary

Torque Margin	41699.44 lbf-ft
Stretch	199.36 in
Windup	4.07 rev
Friction Torque	0 lbf-ft



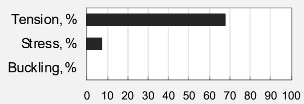
Drilling Sliding

Stretch	205.85 in
SOW Margin	43.45 tonf



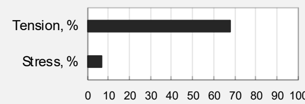
Running In

Stretch	205.85 in
Drag	0 tonf
SOW Margin	43.45 tonf



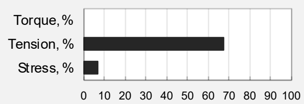
Pulling Out

Overpull	63.56 tonf
Stretch	205.85 in
Drag	0 tonf



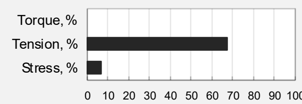
Reaming

Torque Margin	45199.44 lbf-ft
Stretch	205.85 in
Windup	0 rev
Drag	0 tonf
Friction Torque	0 lbf-ft



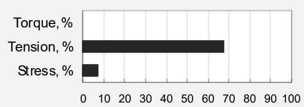
Back Reaming

Torque Margin	45199.44 lbf-ft
Overpull	63.56 tonf
Stretch	205.85 in
Windup	0 rev
Drag	0 tonf
Friction Torque	0 lbf-ft



Rotating Off-Bottom

Torque Margin	45199.44 lbf-ft
Stretch	205.85 in
Windup	0 rev



Tension, stress and buckling while tripping in and out (12 ¼" section)

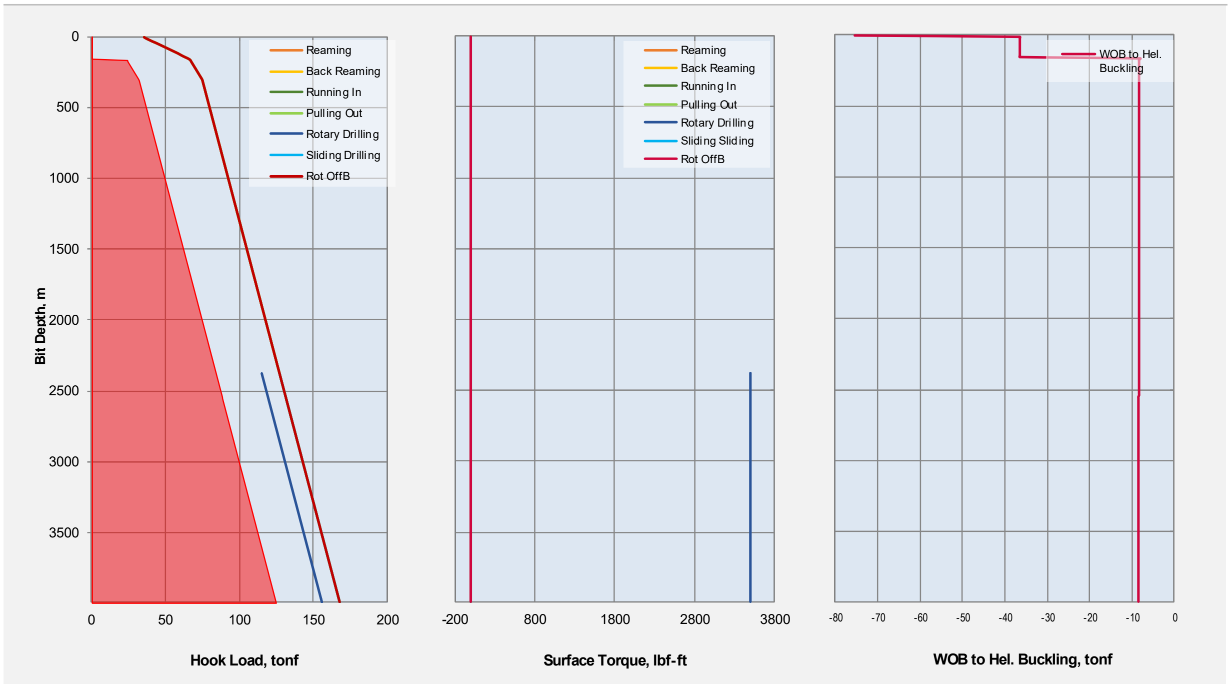
Analysis Settings

Well Depth, m	3992
Mud Weight, sg	1.2
Rig Hoisting Limit, tonf	30
Max Rig Torque, lbf-ft	35000
Rig Torque Setting, lbf-ft	28000

Operational Settings (Average Parameters)

Activity	WOB tonf	TOB lbf-ft	ROP m/hr	Surf. RPM rpm
Rotary	12	3500	5	80
Sliding	0		0	

Activity	RS m/min	Surf. RPM rpm
Running In	10	
Pulling Out	10	
Rot Off Btm		80
Reaming	18.29	60
Back Reaming	18.29	60



Hook load and surface torque distribution (12 ¼" section)

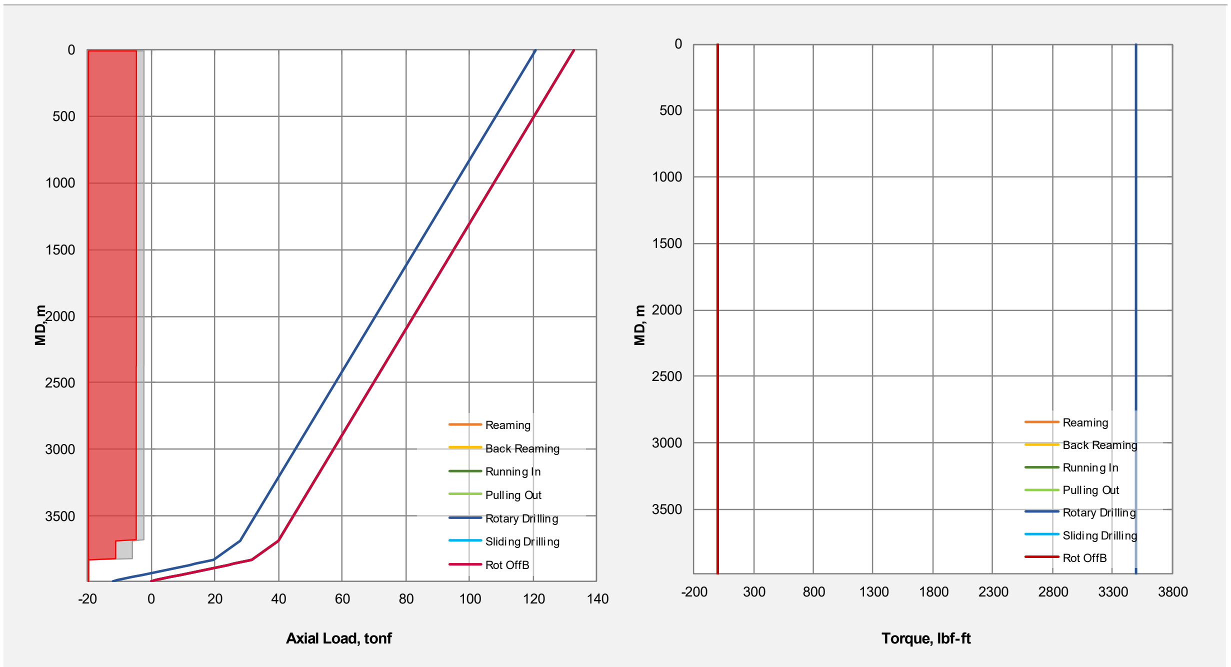
Analysis Settings

Well Depth, m	3992
Mud Weight, sg	1.2
Rig Hoisting Limit, tonf	30
Max Rig Torque, lbf-ft	35000
Rig Torque Setting, lbf-ft	28000

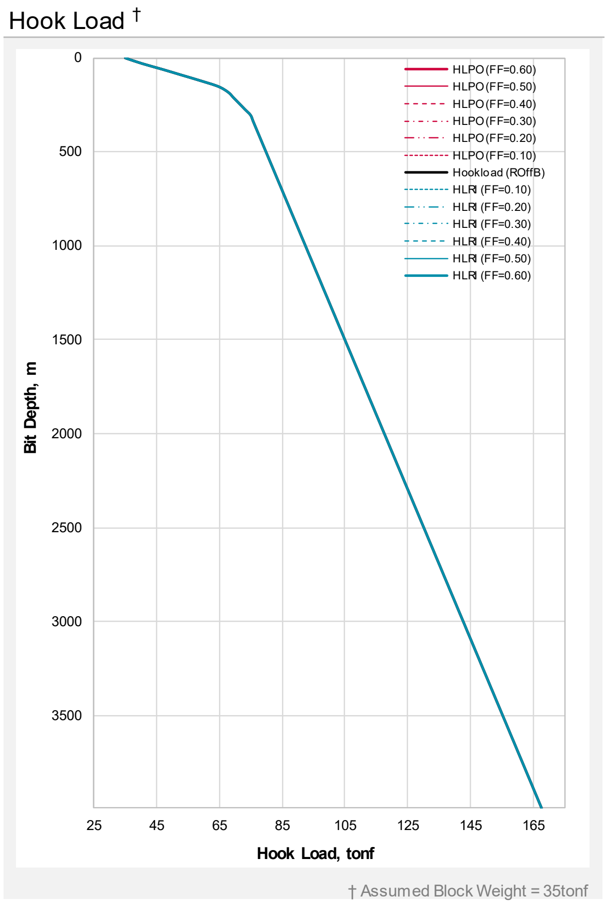
Operational Settings (Average Parameters)

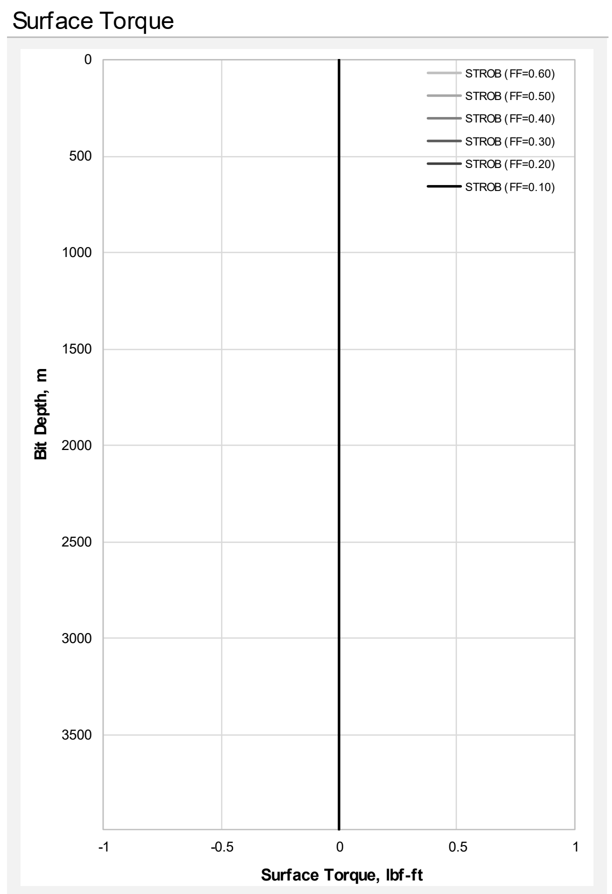
Activity	WOB tonf	TOB lbf-ft	ROP m/hr	Surf. RPM rpm
Rotary	12	3500	5	80
Sliding	0		0	

Activity	RS m/min	Surf. RPM rpm
Running In	10	
Pulling Out	10	
Rot Off Btm		80
Reaming	18.29	60
Back Reaming	18.29	60

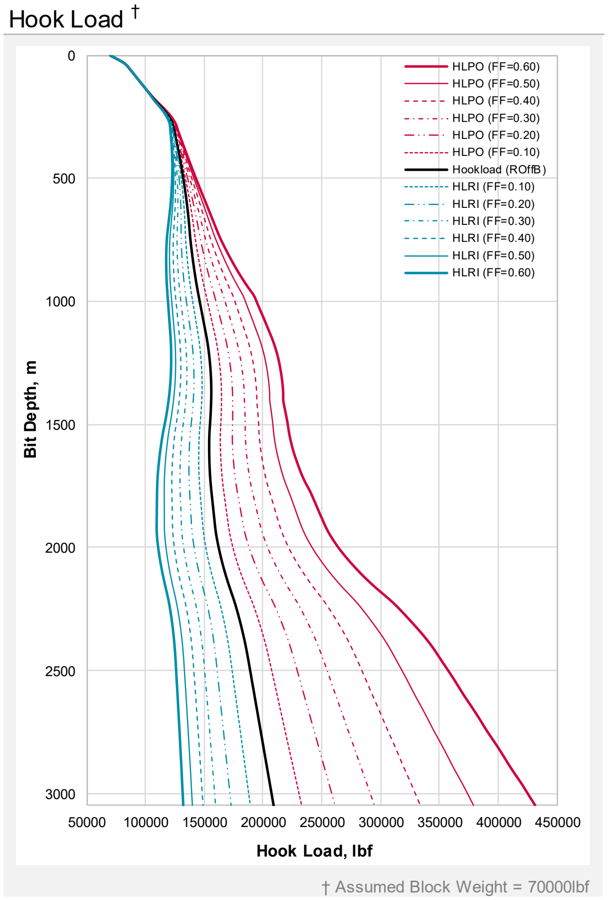


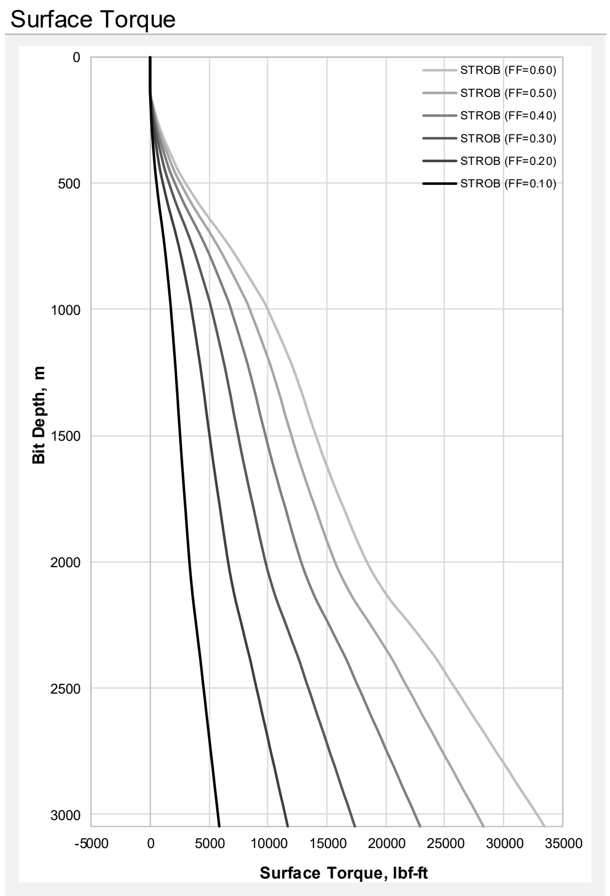
Axial load and torque while drilling process (12 ¼" section)





Hook load and surface torque distribution while drilling process (12 ¼" section)





Friction factor sensitivity charts