Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Geoscience and Petroleum

Ramal Nadirov

Data While Tripping

Using DWT to monitor the borehole condition while tripping to optimize and increase tripping speed and monitoring of EMW while tripping to see any changes in pressure downhole.

Master's thesis in Petroleum Engineering
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Summary

This report has been designed to give the reader detailed information about Data While Tripping as well as modelling tripping speed by considering achieved pressure ranges. The top priority has been focusing on delivering comprehensive explanations. The major goal is for the reader with little or no prior knowledge of the DWT technology to be able to completely comprehend technical properties of DWT.

By development of DWT tool, need for personnel in the red zone was abolished; time savings were also proven. During tripping operations, continuous pressure measurements were supplied via along string measurement tools. To sum up, introduction of the data while tripping device has been a success in the industry for turning the lights on downhole and keeping lights on downhole, which means deploying and utilizing wired drill pipe during tripping operations.

Although DWT is new technology in oil and gas industry, it is becoming more well-known in recent years. In 2020, NOV (National Oilwell Varco) spent significant amount of money to produce new DWT device. As it is part of WDP technology, it is mainly in use with wired drill pipe and along string sensors. The new tool was installed in 2 rigs in the North Sea, and the obtained results such as equivalent mud weight and data on surge and swab effects, were really helpful on determining new faster and safer running operations.

In the report, the beneficial sides as well as working mechanism of DWT tool are discussed detailly. In that purpose, the author used Python coding in order to show and explain the relationship between pressure and tripping speed. In addition, the factors affecting this relationship are represented in thesis too. Besides that, the ecological aspects as well as case studies have been discussed in the report. It is clear from the results from the field cases, such technology is indispensable in managing tripping speed, therefore non-productive time.

Unfortunately, since it is a new technology, it is almost impossible to find real field data to use in the coding. But simulated data has been applied in the Python in order to generate the model. In the report, explanation for coding is given with illustrations of the results.

Acknowledgements

I would like to express my sincere gratitude and thankfulness to my supervisor, Professor Behzad Elahifar, for his great guidance, support, and directions in priceless consultations within the semester throughout the composition of my specialization project. Without his assistance, I am sure it would not have been feasible.

Finally, I want to express the biggest thankfulness to my family, whose continuous support and encouragement allowed me to be where I am. I dedicate this work to my family and to my friends that I see as a part of my family.

Ramal Nadirov

Trondheim, June 2022

List of Abbreviations

ASM – Along String Measurement

BHA – Bottom Hole Assembly

CO_2 – Carbon Dioxide

CO – Carbon Monoxide

DP – Drill Pipe

DWT – Data While Tripping

EDR – Electronic Drilling Recorder

EMS – Enhanced Measurement System

FPWD – Formation Pressure While Drilling

HSE – Health, Safety, and Environment

LWD – Logging While Drilling

MPT – Mud Pulse Telemetry

MWD – Measurement While Drilling

NetCon – Network Controller

NOV – National Oilwell Varco

NO_x – Nitrogen Oxides

NPT – Non-productive time

SO_x – Sulfur Oxides

WDP – Wired Drill Pipe

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1. Introduction

Drilling operations are the most expensive in oil and gas industry. One of the main contests in drilling is about tripping with considering pressure windows. While tripping in and out, there can be rise or fall in bottom hole pressure. It is very important to maintain the pressure value in pressure window. The pressure window is defined by upper limit, fracture pressure and lower limit, pore pressure.

In recent years, oil and gas companies have been trying to operate the well operations in a safe and financially effective manner. Obviously, due to the fractures, depletions, and deep waters, well operations become more challenging in terms of safety and finance. This is why, the industry is focused on developing new technologies and techniques in order to boost the efficiency and effectiveness of wells. For many years, it has been so challenging for the industry to deal with the pressure, by considering Non-productive time, safety, and sustainability, as well as protecting well from kick or fracture. So, there was a need for a new innovation that can reduce the risk for the personnel and regulate the tripping speed. One of the latest developments is Data While Tripping technology, which aims to transfer data with even considering the transfer speed. First, it was deployed on 2 offshore rigs in North Sea for final model checking.

In oil industry, to be aware of the borehole conditions, the tools used were not suitable to measure data while running operations up to now. One of the main challenges is to reduce non-productive time. It is because, finance, emissions as well as pollutions depend on time to great extent. Thus, the longer NPT, the higher amount of cost and damage to the nature. Additionally, in previous years, human contact was necessary in managing the running operations, which was considered very disadvantageous. However, in today's world, new device has been developed and is still in improvement in that purpose.

The tool, which is called as Data While Tripping device, is operated together with wired drill pipe and along string measurement sensors. WDP is the pipe joint with data cables inside, and coils providing connection between joints. By the help of this connection, data transmission is driven from borehole to the surface. ASM sensors can placed anywhere on WDP and mainly measures data on pressure, vibration, rotation, and inclination.

The most crucial beneficial side of the new technique is lack of need to personnel on red zone during the operations. Hence, the automated controls platform is constructed for regulating the tripping speed, without direct contact.

The next thing, DWT tool can be utilized while running in/out, that means reducing time significantly. It is obvious, drilling procedures are the most expensive processes in petroleum industry. That is why, by reducing NPT, industry can benefit in that respect.

When it comes to controlling running speed, this management is based on the formulas and automated calculations. So, by help of tripping speed value, the surge and swab pressures are figured out and then via comparison to pore and fracture pressures the maximal limit for speed is set. On the other hand, by considering cost (NPT), the lowest value of speed is found and the exact range for tripping speed is defined. Setting inaccurate speed for running is very risky, because in case of failure, fracture, you have to spend much more money and time to rebuild your plan.

2. Data While Tripping Technologies

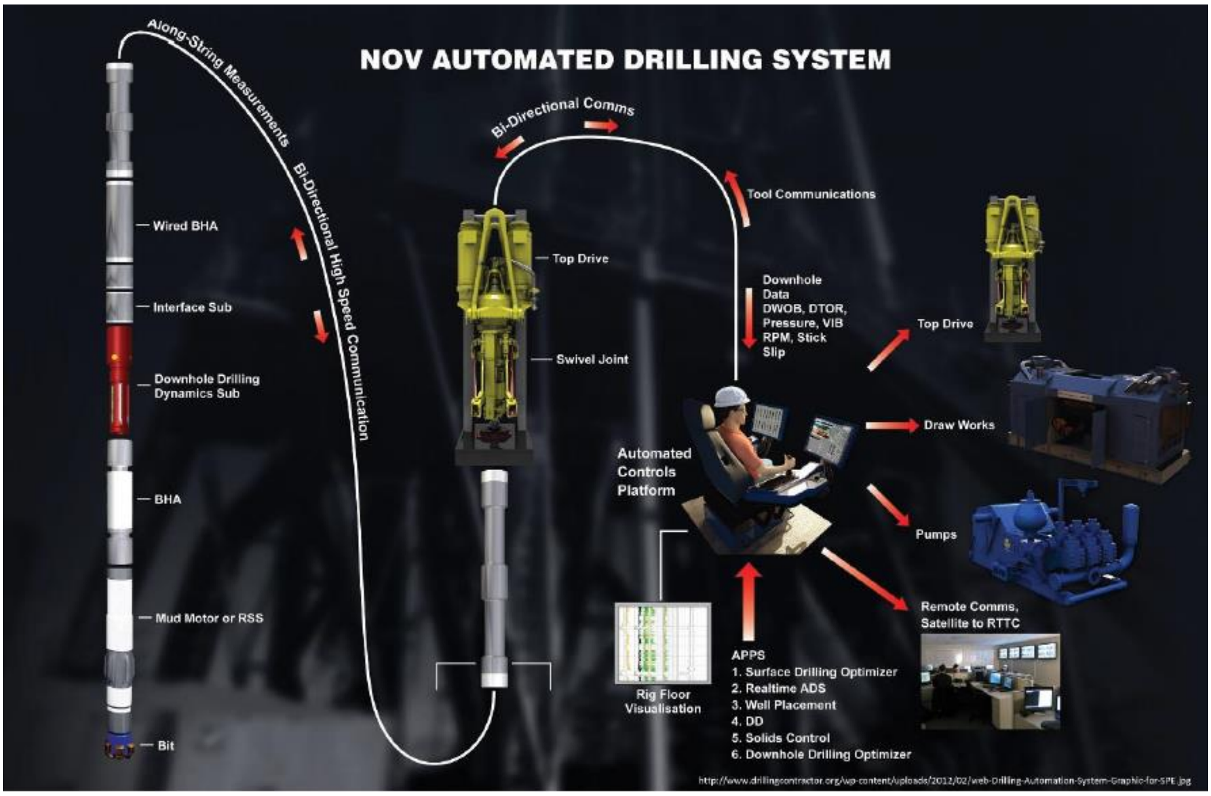

Figure 1-1. NOV automated drilling system. (NOV, 2021)

Companies are constantly challenged with the task of drilling wells safer, faster and with optimized well placement. Utilizing a combination of technologies, such as NOV's IntelliServ wired drill pipe (WDP) network, in addition to an along-string measurement/enhanced measurement system (ASM/EMS) and a data while tripping (DWT) device, helps combat this challenge by providing previously unavailable real-time data during both drilling and tripping operations. This combined technology also eliminates the historical need to pump in or out of hole to collect real-time, high-speed data delivery while tripping. (NOV, 2021)

The WDP and additional M/D Totco tools have been deployed on multiple rigs, and they contributed to optimizing the well execution processes and aided in avoiding critical situations that could have resulted in wellbore abandonment. The measurements streamed by these technologies provided operators with a better understanding of downhole conditions that lead to optimized drilling practices and increased drilling speed.

The authors will describe WDP technology and how data are visualized at the surface. In addition, several case studies will be presented that document a step change in drilling performance for various field development projects and how operators managed wellbore stability and extended reservoir exposure in real time. They also will show the benefits from having real-time swab and surge while tripping on the elevator that allows for faster and safer operations.

2.1. Wired Drill Pipe Technology

Generally, mud pulse telemetry (MPT) is the provider of connection between BHA and top drive, based on the lowest flow rate and opening and closing of the downhole valve. As a consequence, it results in signal of change in pressure. And MPT signal value is mostly dependent on flow rate, depth, and fluid properties. The signal frequency is on average between 5 and 40 BPS. However, WDP can provide data 10000 times faster than MPT. In addition, WDP technology is also very useful in handling downhole environment, because it can provide

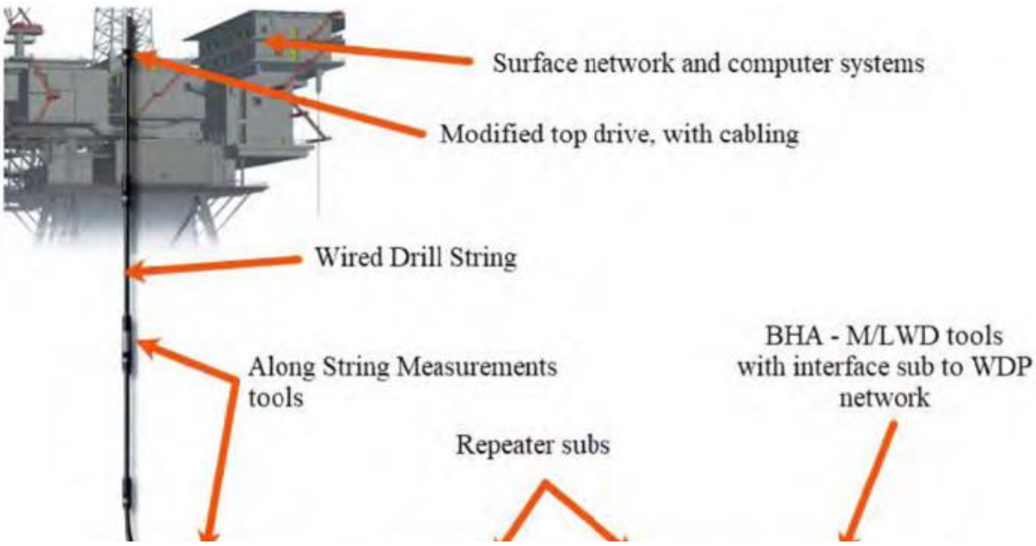

Figure 2-2. Wired Drill Pipe Technology. (Pixton, 2014)

the communication between downhole and surface. Direct data transfer minimizes the interruptions during drilling time. This means reduction in cost. It is clear that, drilling operations is one of the most expensive operations in oil & gas industry.

2.2. The WDP network

In order to achieve the data transfer, it is important to set some equipment between surface and downhole. More precisely, the components that must be installed to use WDP are Data swivel, Data Links, Network Controller, wired drilling components (subs, jars, and accelerators), interface sub, and repeater subs. repeater subs that is positioned about every 1000 ft. On the surface, there is a cabling system with junction boxes that provide control over network. Top drive swivel is the main link under top drive and plays an important role in transferring data from drill string to the surface. The data transfer is conducted via the sub, which is a part of swivel.

As there is a system for WDP, then it must be controlled automatically and regularly. NetCon, which is network controller is specialized in acquiring, translating, and transferring data to users. This tool is very beneficial in monitoring and maintaining the data transfer by WDP.

The data swivel is installed on top drive, and it is the uppermost part of WDP network. As a result, this swivel serves as a link between the downhole and surface networks. Data is

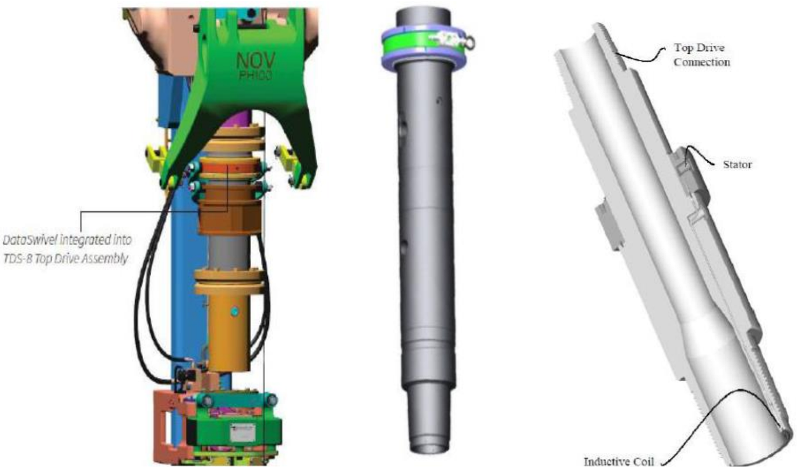

Figure 2-3. Data swivel; Intelli Coils. (Babu, 2019)

sent from the BHA to the swivel via the data cable and Intelli Coils along the drill string, where it is sent to the NetCon via the surface cabling.

Additionally, the other part of the WDP is wired pipe, which looks like normal pipe, but its main difference than the others is its additional components that can provide the network from borehole to surface. In the figure below, the main parts and the way of data transmission is represented. As it is clear from the picture, data cable is a crucial part of wired pipe, and enables the fast transmission of data. What is more, at the beginning and end of the pipe, there is Intelli Coils that allows bidirectional data transfer, thus makes the data passing from one joint to the next.

ASM tools are also available in this system and providing data on pressure, temperature,

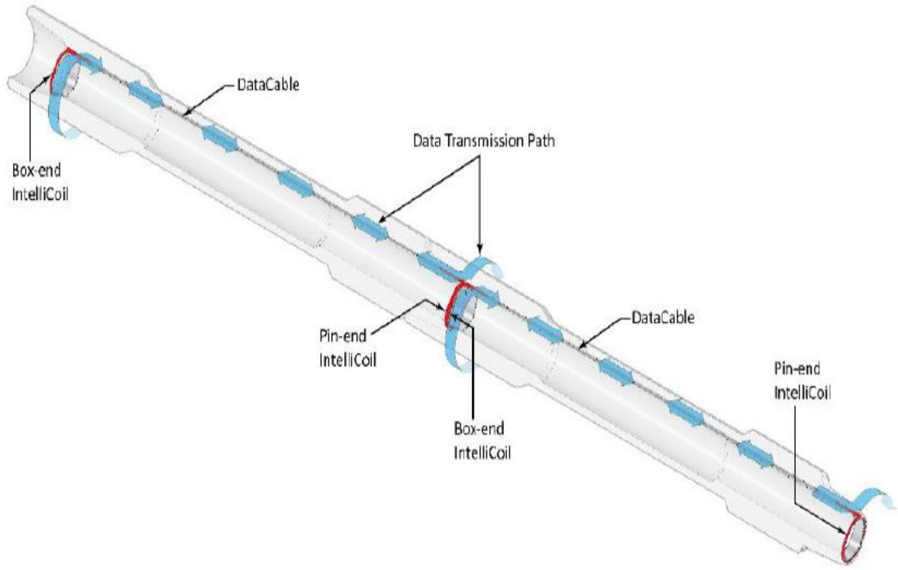

Figure 2-4. Intelli Coils (Babu, 2019)

and vibration along the drill string. EMS, which is enhanced measurement system provides the same data, but with also downhole torque and WOB.

2.3. Datalinks

Datalinks possess the function of boosting and repeating the signal which are fixed along the drill string in order to provide proper ratio of signal to noise. When the signal transfers along the string, it starts to lose energy and its strength becomes weaker. Datalinks have batteries and they are supplied with electronic devices which are intensifying the data signal passing along the WDP network in order to make the surface devices able to proceed the data. The location and frequency of placement of repeaters of Datalink along the drill string relies on string length, but generally these repeaters are placed in every 300-450 meter or 10-15 section of drill string. (NOV, 2021)

2.4. Interface Sub

Interface sub makes enable the network of wired drill pipe to obtain and transfer data to RSS and L/MWD equipment. This sub is equipped with electronic devices which generates the connection from WDP network and third part providers. In terms of transmission of data between companies' devices, there are minor variations in each company which has connection to WDP network. (Russel, 2008) So, interface subs have downhole and up hole connections where downhole connection is set for obtaining data from devices while up hole one generates contact with the network. In order to make the data transmissible to the surface equipment, the interface sub is equipped with modem board which converts the data signal. Because of this connection, The MWD/LWD/DD engineers can effectively manage and access functionality because the tools were linked to their systems at the surface.

2.5. Along String Measurement

In general, ASM tools can be placed anywhere along the drill string till the BHA, using WDP network technology. Mainly, some physical factors such as pressure, stress, and rotation can be easily measured by help of along string measurement sensors. Apart from that, these sensors are useful on getting information about inclinations and azimuths. Although, ASM tool is introduced to the industry recently, with proper development, it can be most likely more consistent in the near future.

Figure 2-5. Along String Measurement tool. (Babu, 2019)

For many years, the oil industry was restricted to measuring only in the BHA and on the surface. for forecasting conditions, pre-drilling simulations are heavily utilized in wellbore areas whilst measurements are unavailable. The use of sensors that can be placed anywhere along the well allows observation and monitoring of the downhole environment not only in the BHA but throughout the entire borehole. (Coley, 2013)

To take merit of the WDP network, array measurement (ASM) tools have been developed. These tools, like Datalinks, are signal boosters that can be placed anywhere on the drill string, but ASMs are outfitted with sensors that measure triaxial vibrations, rotation, temperature, internal and circular pressure. Because ASMs are battery-powered, they can ensure real-time stream readings. ASMs take high frequency measurements (0.5Hz) and forwarded them to the surface at high speeds (57.6 Kbps). This data ensures critical information concerning hole cleanliness/quality, allowing you to make informed decisions and avoid drilling risks including such damaging vibrations as well as well stability issues (Salomone, 2019)

The WDP network has been presented thus far. The benefits of having a high-speed telemetry channel, as well as the new tools WDP was able to deploy throughout the series, were discussed. This telemetry and tool combination has been in utilize for nearly a decade. Drilling efficiency has increased, drilling operations have improved, HSE risks have been diminished, and well times have been shortened as a consequence of the outcomes and practices (Vandvik, 2014).

2.6. Formation Pressure While Drilling

In general, there are two challenges for driller, more precisely kicks and losses. In order to overcome such challenges, mud weight optimization is crucial. So, till now, a lot of technologies have been engaged into the industry to measure pressure. (M, 2007) However, it is not that easy to do so easily. This why, there is need for FPWD tool. Nonetheless, there is still a lack of knowledge of how such technologies might decrease hazards in specific places and enterprises. Some argue that gauging formation pressure "behind the bit" is too late to correct the problem and prevent kicks and losses.

The FPWD instrument measures formation pressure and mobility directly in real time. The tool is a probe type formation tester, with a design and operation that is comparable to that of traditional wireline formation testers. The measuring probe is advanced to the desired test depth, the bottom hole assembly (BHA) is kept fixed during the pretest, and the measurement is communicated to the surface.

Figure 2-6. Probe type formation tester. (Babu, 2019)

A downlink command is delivered to the measurement while drilling (MWD) tool and passed to the FPWD tool for FPWD pretests; this command contains instructions on which pretest sequence to execute. The settings of the pretest may be fixed or downhole variable, depending on the sequence required. Fixed pretests are chosen based on expected formation mobility and will "fix" the rate, volume, and time for the pretest sequence. Fixed Mode pretests can be dangerous due to uncertainty in formation mobility, but the ability to adjust the rate and volume directly can be advantageous in diverse formations.

The tool has several applications in some areas, such as reservoir management, drilling optimization, well placement. In the figure below, it is much more obvious to see the areas for use of FPWD tool:

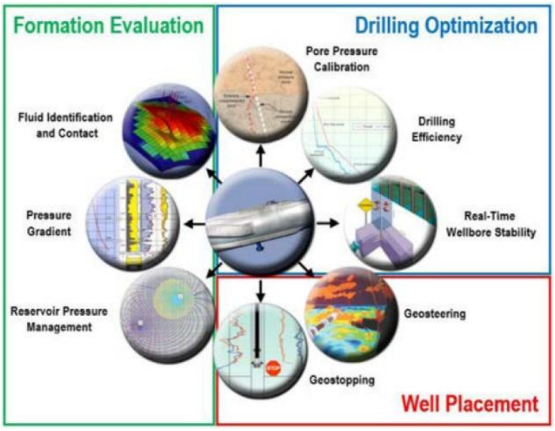

Figure 2-7. FPWD use areas. (Seifert, 2008)

2.7. Data While Tripping

Obviously, if there is no connection between drilling and top drive during tripping operations, then data transfer is completely impossible. For many years, it's been considered really significant lack in technology. So, plan and initial model of Data While Tripping device got introduced to the industry in 2020s.

Up to now, the primary sources of data from bottomhole have been MWD (Measurement While Drilling) and LWD (Logging While Drilling). The working mechanism of them is based on the physical and software link between BHA and WDP (Wired Drill Pipe), which is provided by interface sub. Normally, the data is transferred from sensors to the mud pulse assembly.

WDP evolution, which means the possibility to record data on pressure, temperature vibration and etc. with ASM, was issued in 2013 (Craig, 2013). However, the tripping operations are still problematic that because of the disconnection with top drive during tripping causes network loss. Additionally, lack of awareness of surge and swab, sign of hole drag as well as troubles with downhole measurement tools results in rise of NPT (Non-productive time). Previously, only access to the pressure data was provided by WDP. But it must be connected to the top drive. Then, in 2019, new DWT equipment was introduced and utilized on 2 rigs in North Sea. Via the continuous connection with downhole allowed to get control over tripping speed according to the pressure measurements. That is why, it became easy to minimize risk of surge and swab.

The next and most important dilemma is about safety of personnel. Thus, there was a need for person to be in red zone, which may put health and life under risk. Because of these difficulties, there have been a requirement for a technology like Data While Tripping. It is mostly proved that introduction of DWT device will provide usage with assistance of wired drill pipe (“Turning the lights on downhole”) and make connection available during tripping operations (“Keeping the lights on downhole”). As it is mentioned before, till now the WDP required the link between drill string and top drive in order to record data properly. In addition, to make sure on signal permanence, manual tests were required during tripping in operations (Mats Andersen, Sanna Zainoune, Eirik Vandvik, 2021).

2.8. DWT tool

As for DWT device, it is highly beneficial on decreasing time spent for testing system with increased testing frequency as well as the risk and need for personnel to be in red zone. Apart from these, it allows to transfer data from WDP directly and screen surge/swab effect.

There are a few designs and properties for DWT tool model. Thus, in addition to mentioned considerations, the weight of tool (should be handled by personnel easily), activation without spending too much time, possibility to work with numerous WDP as well as matching

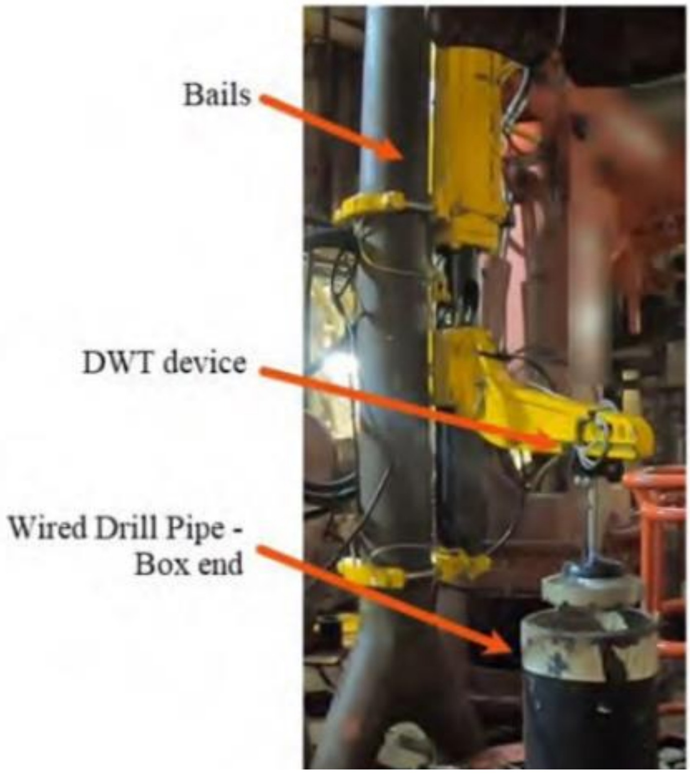

Figure 2-8. Data While Tripping tool (Jeffery, C., Pink, S., Taylor, J., & Hewlett, R. , 2020)

several rig configurations such as top drive and elevator. Furthermore, model is designed to be controlled by a viewer even from driller's cabin (Christopher Jeffery, 2020).

2.9. Data Visualization

When the WDP and ASM are used together, then the data transfer is boosted significantly. The data is collected in EDR (Electronic Drilling Recorder) and then delivered to the operational teams to analyze and plotted according to the time and depth. The working mechanism of DWT tool is mainly based on the measurements from sensors that placed at different inclinations. Generally, they transfer data on time, depth, and real-time measurements. (Salamone, 2019)

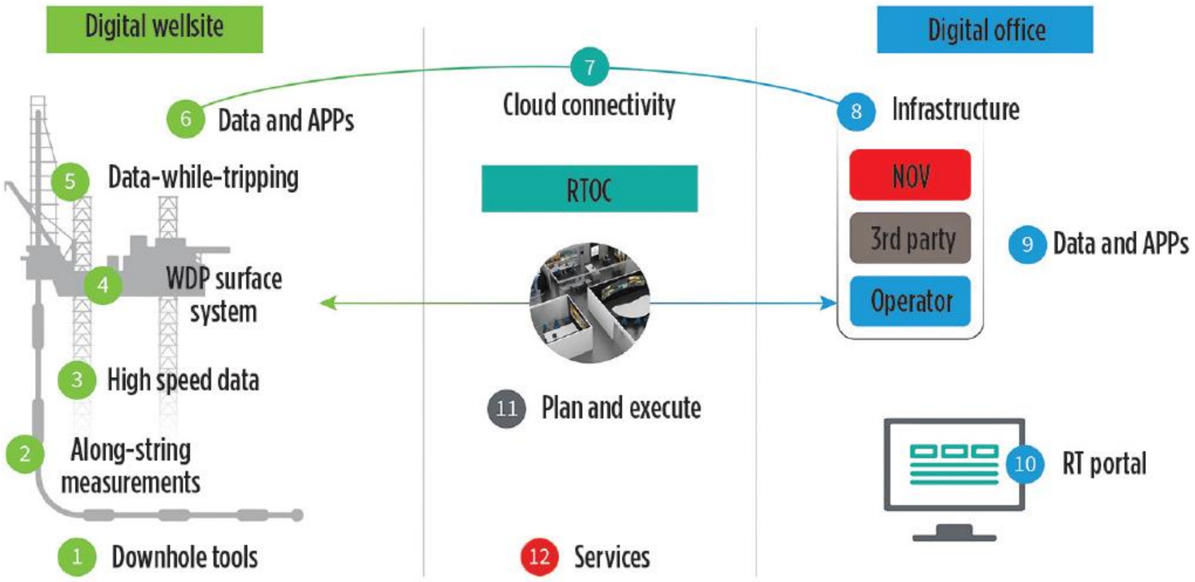

Figure 2-9. Digital data transfer. (Jeffery, C., Pink, S., Taylor, J., & Hewlett, R. , 2020)

3. Theory & Formulas

3.1. Surge and Swab Pressure

This part of the report is about controlling trip speed. Although rig operation time plays very important role in that purpose, it is not the most concerning factor. In order to handle trip speed, it is crucial to acquire swab and surge pressure values. Surge is generated by additional high pressure in the wellbore during running-in. If that pressure gets so high, then it can lead to fracture of formation. On the other hand, swab effect is due to the vacuum generated in case of running-out. And the worst scenario of swab effect can be kick.

3.2. Tripping speed optimization

In oil industry, one of the most important challenges is to deal with pressure and to predict the wellbore pressure precisely. It is because, thanks to such predictions, it becomes easy to prevent kick, blowout, or something dangerous. During tripping operations, pressure change occurs and therefore causes several stability and integrity problems. There are some parameters that can affect surge and swab, such as tripping speed, wellbore geometry as well as fluid properties. For example, fluid with high viscosity makes the flow difficult and therefore tripping speed is supposed to get lower. In terms of geometry, the clearance between drill string and well is so important. So, the surge and swab effect increase in case of decrease in annular clearance. When it comes to the tripping speed, its optimization is so vital. Risk of influx, kick and therefore blowout increases in case of high tripping speed. It is obvious that the higher the speed, the higher the pressure change. On the other hand, if the tripping speed is too small, then rig time and expense rises in order. The tripping speed is the only factor that can be controlled on the rig site. So, it is important to control tripping speed by considering both statements in order to avoid from formation damage and such financial and time-wasting problems. That is why, precise estimation of pressure change is very crucial.

In that purpose, the first issue is to figure out the dependence between differential pressure and tripping speed. There are several equational models to determine the relationship between surge/swab pressure and tripping speed and create new tripping speed model in order to optimize tripping action as well as the operation time.

3.3. Method 1

The first and conventional technique to determine pressure is based on the relation and conversion between pipe running speed and fluid velocity (Lapeyrouse, 2002):

The first step is to evaluate the pressure drop around the drill pipe (DP).

$$n = 3.32 \log \frac{\theta 600}{\theta 300} \qquad (1)$$

$$\theta 600 = Plastic\ Viscosity + \theta 300 \quad 2$$

$$\theta 300 = Plastic\ Viscosity + Yield\ Point \quad 3$$

$$K = \frac{\theta 300}{511^n} \quad 4$$

$$v_{fluid} = \left(0.45 + \frac{OD_{pipe}^2}{D_{hole}^2 - OD_{pipe}^2}\right) * v_{pipe} \rightarrow \text{closed-ended pipe} \quad 5$$

$$v_{fluid} = \left(0.45 + \frac{OD_{pipe}^2 - ID_{pipe}^2}{D_{hole}^2 - OD_{pipe}^2 + ID_{pipe}^2}\right) * v_{pipe} \rightarrow \text{open-ended pipe} \quad 6$$

$$v_{max} = 1.5 * v_{fluid} \quad 7$$

$$\Delta P_{dp} = \left(\frac{2.4 * v_{max}}{D_{hole} - OD_{pipe}} * \frac{2n+1}{3n}\right)^n * \left(\frac{K * L}{300(D_{hole} - OD_{pipe})}\right) \quad 8$$

In the next step, the pressure loss around the drill collar is to be calculated.

$$v_{fluid} = \left(0.45 + \frac{OD_{collar}^2}{D_{hole}^2 - OD_{collar}^2}\right) * v_{pipe} \rightarrow \text{closed-ended pipe} \quad 9$$

$$v_{fluid} = \left(0.45 + \frac{OD_{collar}^2 - ID_{collar}^2}{D_{hole}^2 - OD_{collar}^2 + ID_{collar}^2}\right) * v_{pipe} \rightarrow \text{open-ended pipe} \quad 10$$

$$v_{max} = 1.5 * v_{fluid} \quad 11$$

$$\Delta P_{dc} = \left(\frac{2.4 * v_{max}}{D_{hole} - OD_{collar}} * \frac{2n+1}{3n}\right)^n * \left(\frac{K * L}{300(D_{hole} - OD_{collar})}\right) \quad 12$$

The total pressure loss is equal to sum of these pressure drops.

$$\Delta P = \Delta P_{dp} + \Delta P_{dc} \quad 13$$

$$P_{surge} = P_{hydrostatic} + \Delta P \quad 14$$

$$P_{swab} = P_{hydrostatic} - \Delta P \quad 15$$

3.4. Method 2

The next method is calculation of swab and surge pressure based on fluid flow equations. In this method, critical and average flow velocity around the collar and pipe must be evaluated in order to define if the flow regime is laminar or turbulent by the help of the comparison between average and critical velocity. By doing so, the next step is to figure out the pressure drop. (Gatlin, 1960)

$$V_{critical} = \frac{1.08\mu_p + 1.08\sqrt{\mu_p^2 + 9.3\rho(D_{hole} - OD)^2 Y_p}}{\rho(D_{hole} - OD)} \quad (16)$$

$$V_{average} = V_{pipe} * \left(\frac{1}{2} + \frac{OD^2}{D_{hole}^2 - OD^2}\right) \quad (17)$$

$$V_{average} > V_{critical} \rightarrow \text{Turbulent flow} \quad (18)$$

$$V_{average} < V_{critical} \rightarrow \text{Laminar flow} \quad (19)$$

$$\Delta P_{laminar} = \frac{L}{300(D_{hole} - OD)}\left(YP + \frac{\mu_p V_{average}}{5(D_{hole} - OD)}\right) \quad (20)$$

$$R_e = \frac{2790\rho V_{average}(D_{hole} - OD)}{\mu_p} \quad (21)$$

$$f = e^{\left(C1 + \frac{C2}{R_e}\right)} + C3 * \ln(R_e) \quad (22)$$

$$C1 = -3.5378591164$$

$$C2 = 300.26609292$$

$$C3 = -0.126153971$$

$$\Delta P_{turbulent} = \frac{f L \rho V_{average}^2}{25.8(D_{hole} - OD)} \quad (23)$$

$$\Delta P = \Delta P_{dp} + \Delta P_{dc} \quad (24)$$

$$P_{surge} = P_{hydrostatic} + \Delta P \quad (25)$$

$$P_{swab} = P_{hydrostatic} - \Delta P \quad (26)$$

After calculating the pressure drop, and therefore precise plotting of surge/swab pressure versus pipe tripping speed, fracture pressure (the highest limit) and the pore pressure (the lowest limit) should be considered. As a consequence, the range for swab/surge are obtained and pipe running speed can be regulated in order to stay in that range. But, in that purpose, the fracture pressure and pore pressure must be evaluated according to given data. At the end, by considering fracture and pore pressure and therefore setting pressure limits, the maximal value for tripping is easily obtained.

The diagram on the next page is constructed according to the equations and conditions represented above. On the further calculations and crating tripping speed model via special programming languages, this diagram is very essential.

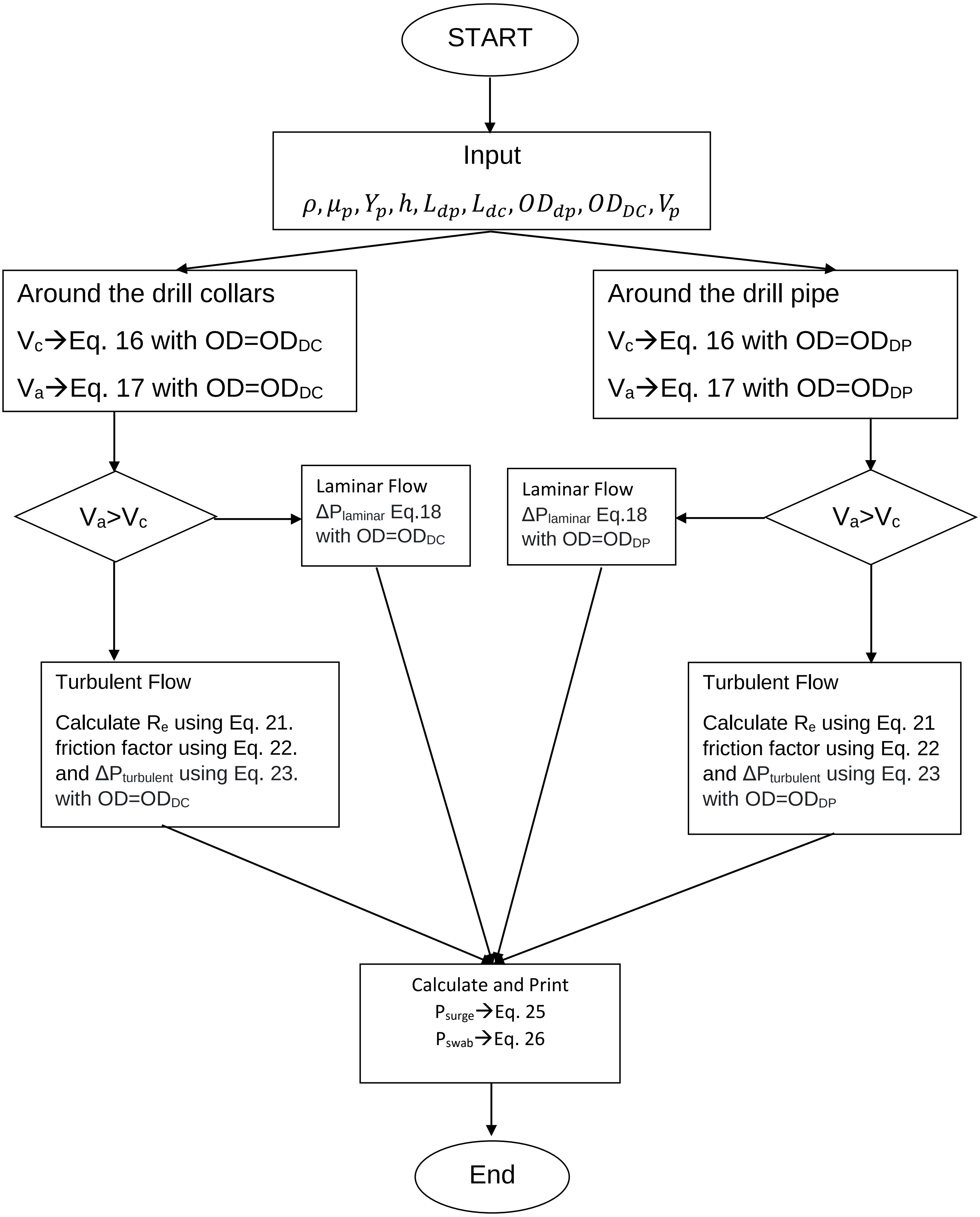
START
Input
$\rho, \mu_p, Y_p, h, L_{dp}, L_{dc}, OD_{dp}, OD_{DC}, V_p$
Around the drill collars
V_c → Eq. 16 with OD=OD_{DC}
V_a → Eq. 17 with OD=OD_{DC}
Around the drill pipe
V_c → Eq. 16 with OD=OD_{DP}
V_a → Eq. 17 with OD=OD_{DP}
$V_a > V_c$
Laminar Flow
$\Delta P_{laminar}$ Eq.18
with OD=OD_{DC}
Laminar Flow
$\Delta P_{laminar}$ Eq.18
with OD=OD_{DP}
$V_a > V_c$
Turbulent Flow
Calculate R_e using Eq. 21.
friction factor using Eq. 22.
and $\Delta P_{turbulent}$ using Eq. 23.
with OD=OD_{DC}
Turbulent Flow
Calculate R_e using Eq. 21
friction factor using Eq. 22
and $\Delta P_{turbulent}$ using Eq. 23
with OD=OD_{DP}
Calculate and Print
P_{surge} → Eq. 25
P_{swab} → Eq. 26
End

Table 3-1. Python Simulation Data

Python simulation data				
Parameter	Value	Unit	Value	Unit
Mud weight	11	ppg	0.572	psi/ft
Mud plastic viscosity	35	cp	5.0763E-06	psi*sec
Yield Point	100	lb/100sq.ft	100	lb/100sq.ft
Well depth	11000	ft	11000	ft
Hole diameter	8.875	inches	0.73958333	ft
DC/DP ratio	0.1	-	0.1	-
Drill Pipe Outer Diameter	4.5	inches	0.375	ft
Drill Collar Outer Diameter	6.75	inches	0.5625	ft
String Tripping speed	12.42	ft/sec	12.42	ft/sec
Pore Pressure gradient	0.45	psi/ft	0.45	psi/ft
Fracture Pressure gradient	0.67	psi/ft	0.67	psi/ft
Poisson's ratio	0.25	-	0.25	-
Overburden Pressure	0.96	psi/ft	0.96	psi/ft

The first step is to transfer the equations with the assumed data into the Python programming language. So, the pressure drops for both drill collar and drill pipe are calculated and summed in order to figure out swab and surge pressures after tripping actions. The result of the coding is represented in a graph below. It is pretty clear from the graph that the maximal tripping speed has to be set to 12.42 ft/sec. As it is mentioned in the report, there are two main conditions that should be considered while optimizing tripping speed, financial and ecological aspect. In order to avoid from much environmental damage, the tripping speed should be as much as possible. It is also clear that drilling operations are so expensive, that is why, the range for tripping speed has to be high to avoid from time wasting.

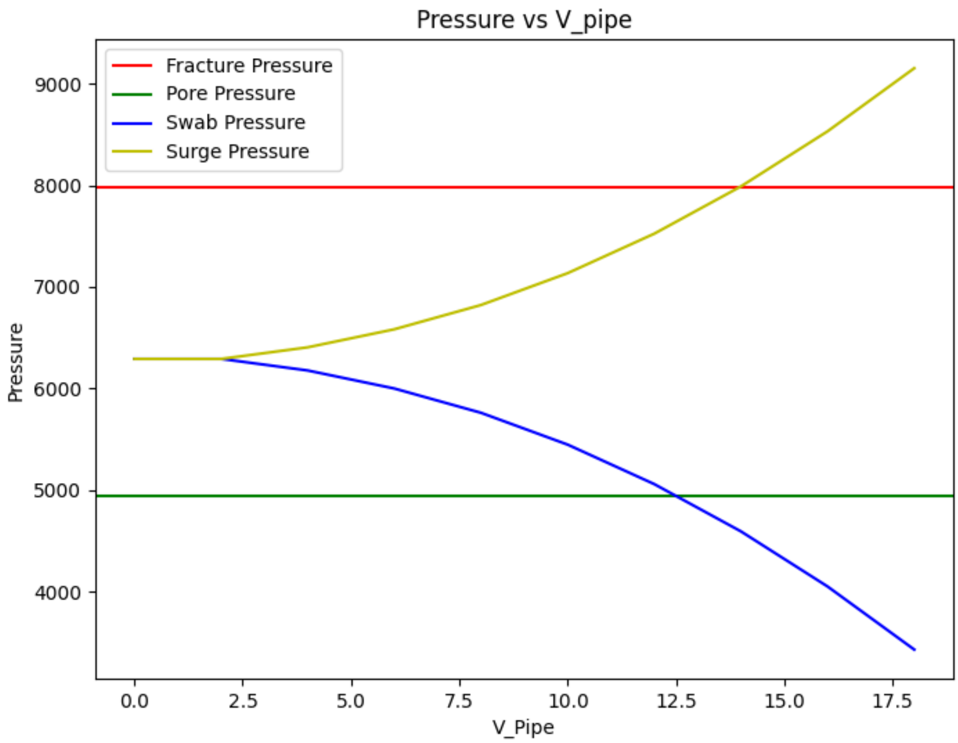

Figure 3-1. Python Output - Pressure versus Tripping Speed

4. Parameters affecting surge and swab pressure

4.1. Tripping speed

Simple wells that are already drilled have been confirmed by researchers and several field experts and only difficult wells are left. These kinds of problems contain the wellbore stability, depleted formations and the narrow gap between pore pressure and fracture. "Drill string" that trips out of the hole quick and unexpectedly decreases the wellbore pressure. Also because of the force of friction between the upward moving of pipe and the stationary drilling mud, defined as the "swab" pressure. The opposite is also correct, it is going to result in a pressure increase by moving rapidly within the wellbore, and this is called the "surge" pressure. Both of those mentioned pressures ("swab" and "surge") can cause some drilling problems such as wellbore influx and drilling fluid losses. When the "BHA" is running in the wellbore, an extra bottom hole pressure is induced which is called surge pressure. Some of the previously described troubles might happen when "surge" pressure is high enough. In other words, swab pressure occurs when the wellbore pressure decreases rapidly.

In order to eliminate these drilling problems, the best estimation of "swab & surge" pressures is essential, especially the parameters that influence them such as the tripping speed. The difficulty becomes bigger for wells that have a limited gap between formation and fracture pressure. The speed of tripping becomes very crucial in deep wells because it requires much time and hence higher costs. Having a model to simulate and measure the maximum speed of running pipe would also be beneficial, thus which we are the attention of the difference pressure we are applying. for calculating any pressure dropping in the wellbore without a tripping margin, which is recommended to be added without simulation. Depending on the well type, the value is usually between 100 and 300 psi. The disadvantage is to not recognize the suitable tripping speed which will reduce cost and save time, or not to understand if the value of the tripping margin is adequate. We should consider the wellbore stability for choosing the speed of tripping. It is going to help us to clarify if it is within the boundaries of well-bore geo-mechanics. The high surge pressure might result in fracture formation, which would lead to hydrostatic mud column loss. Fractured formation allows mud column inside the formation for being lost.

Hydrostatic pressure decrease exerted on the formation, allows the well to flow and to create a well control issue. If the drill string is pulled out of the well, it would simulate the piston or syringe effect where the mud is raised to the up. The formation pressure is no longer resolved by the hydrostatic column of mud. Fluid which gets in the borehole creates a kick which contributes to a blowout is a critical threat (Al-Abduljabbar, 2018).

4.2. Fluid Properties

4.2.1. Drilling fluid

In drilling engineering, the mud system is very important and has a lot of essential functions. Muds are pumped through the drill string, after that out from the bit nozzles, and then they bring the formation cuttings from the bottom hole to the surface through the annulus. Next, it goes to a shaker, in which the cuttings are washed out, and mud returns back to the mud tank. Hence, the cleaning of the hole and the removal of cuttings is not the only feature of the mud. The drilling mud is generally consisted of water, clay and additives. The main goal of using the drilling fluids is lifting the formation cuttings and oil is generally used as the continuous phase to obtain specific features. However, drilling fluids are also considered to be critical when it comes to maintain the formation pressure in the well underneath control. The pressure that is exerted by mud on well wall depends on the mud's density. The dense it is, the more pressure it imposes on it. Hence, the weighting materials such as "barite" can be added in order to increase the pressure which the mud imposes (Coussot, Philippe, F. Bertrand, and B. Herzhaft., 2004).

4.2.2. Advantages of Drilling Fluids

- They move the drilling cuttings mechanically out of the well until those cuttings are recycled in the well-bore again in order to maintain the hole clean.
- They maintain a controlled pressure of formation and prevent any hydrostatic forces that may damage the drilling activity
- They supply the walls of the wellbore until they are cemented, or the equipment is completed and mounted
- They are used for drill string lubrication and cooling
- For transmission of hydraulic horsepower for the bit
- They are used to enable the information about the wellbore through the study of the cutting's transportation.

4.2.2.1. Water-Based Muds

Four components of water-based mud are known: chemicals, inert solids, water and colloidal solids. The continuous phase of water-based mud indicates water. It can be used to make the initial viscosity, and the rheological features can be changed by additions. In the continous phase, some reactive solids such as inert solids and bentonite are suspended as well. Water serves as a mediumfor the horsepower transport from the surface to the bit. In order to raise the viscosity of the water-based mud, clay is used because it increases the density, yield point and consistency of the gel and decreases the fluid loss. In drilling fluid, the clay can be divided into three parts:

- Montmorillonites
- Kaolinite
- Illite

4.2.2.2. Oil-Based Muds

The oil-based mud is defined as any drilling mud that contains appropriate oil as a continuous phase. Two kinds of system exists where oil is considered to be a continuous phase: real mud oil and mud emulsion consist of the following components:

- Suitable oil.
- Water.
- Asphalt.
- Surfactants.

- Emulsifiers.
- Weighting materials.
- Calcium hydroxide.
- Other chemical additives.

To function oil-based mud, the first one is essential among all other components. Some simple plastering features and rheological properties are only applied to the remaining components to improve. Even though water is not necessary between the oil mud systems constituent, some unique rheological features can also be applied with some other chemical additives for improvement. In order to find a particular filtration loss feature, numerous body additives are used in oil muds. These activities may be divided into two groups:

- Collodial materials size
- One of the colloidal sized organophilic substances was used in oil muds in order to decrease fluid loss which happened as a result of its absorption properties. It is basically the same principle of clay in water mud. In the same time, emulsifiers are added into oil muds to invert emulsion operation in the type of dense metal fatty acid soaps. The objectives of oil mud emulsifiers are:
- Is being able to suspend the cuttings containing the gel, to pass on the strength to the oil muds
- Every drop of the water in the oil mud is emulsified through the drilling process
- Consequently, the loss of fluid is controlled by tightening of any emulsion of water resulting from water pollution

4.2.3. Synthetic-based mud

This type of mud is based on synthetic oil, which is used less and has less toxicity but has almost same properties of an “OBM”.

4.2.4. Drilling fluid properties

The “surge and swab” pressure is based on the flowing of fluid. Some conditions such as pretty high viscosity makes fluid flow hard, which means slower tripping speed is needed to allow fluid to flow. The high gel strength limits flow from static conditions and rises the surge and swab risk throughout running in and pulling out of the hole, the density indicates the most necessary purpose (Forutan, 2011). When the density of mud is too low or too high that affects speed of the tripping which contributes to the swab and surge impact

In order to get a good drilling procedure; the different characteristics of the drilling mud generally play a significant role which are the simplest parameters of the operation. For both the mud method utilized to drill and individual circumstances of the well a well is built. Some of the drilling parameters which are required to identify the key properties according to the American Petroleum Institute (API) are:

- Density.
- Viscosity and Gel Strength.
- Filtration.
- The concentration of sand.
- Methylene Blue Capacity.
- pH.
- Chemical analysis.

4.3. Density

In order to maintain the wellbore pressure within suitable limits, it is necessary to regulate the drilling fluid. If the density is significantly high, the formation will fracture. Otherwise, it could contribute to fluids inflow from the formation. Density of the fluid is the mass per volume, and it is related to the solid specific gravity of the fluid mud weight, expressed in (lb/ft3), (lb/gal), (kg/m3).

Solid formations can be drilled in case of low-density muds, however shale under high pressure, for instance, might require a mud density over 2000 kg/m3. The figure below indicates the density influence on the swab & surge pressure. The surge pressure is raised when density goes up, whereas it reduces with density decrease.

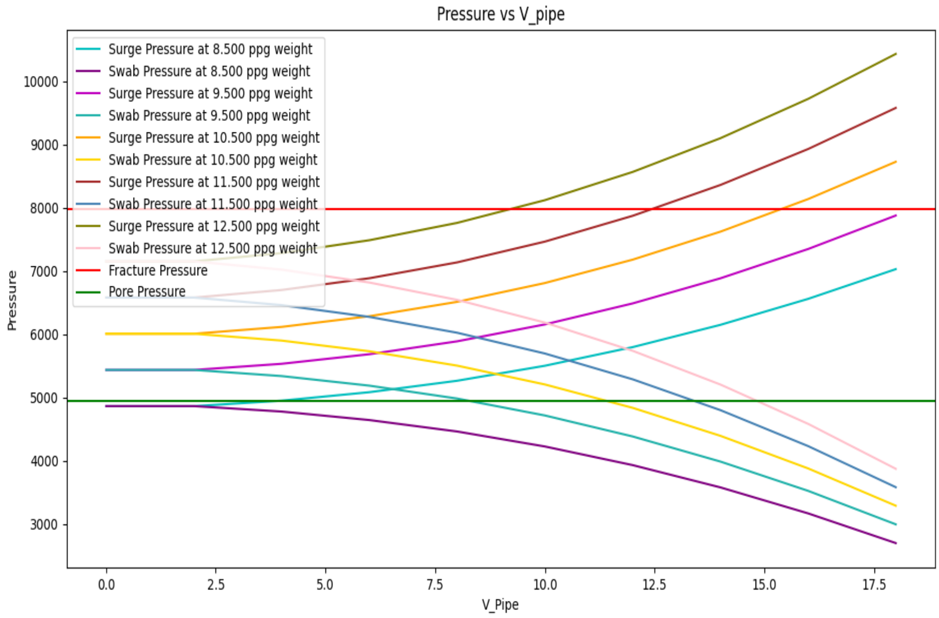

Figure 4-2. Python Output - Changing Mud Weight.

4.4. Viscosity

The viscosity is the measure of the fluid resistance to flow during the deformation through "shear stress". The greater the "thickness" of fluid, the higher the viscosity. By calculating the "shear strength" it is possible to determine the viscosity of fluid by usage of viscometer. This mentioned device is regulated continuously at six normal speeds as a "3,6,100,200,300,600" RPM, and shear stress is calculated for each velocity value. Viscosity is described by centipoise (cp), which is equivalent to 1 "millipascal" multiply by second (mPa s). The drilling fluid viscosity can be improved through the process of drilling with addition of clay or polymers or decreased by adding water or chemical thinners.

Bingham plastic viscosity can be determined by the dial read with usage of viscometer, at 300 and 600 RPM.

$PV = \theta 600 - \theta 300$ (3-1)

Accordingly, amount of viscous cream is higher than water. Indeed, addition of a small amount of material to the solution or suspension will dramatically rise the velocity of liquid. μ is 22 denoted by molecular viscosity; it is expressed in Pa.s or poise. Generally, liquid viscosity is higher than that of gas. Since the liquid molecules are closer together, more frequent interactions are formed between them that increase the assembly cohesion. Viscosity changes inversely with temperature.

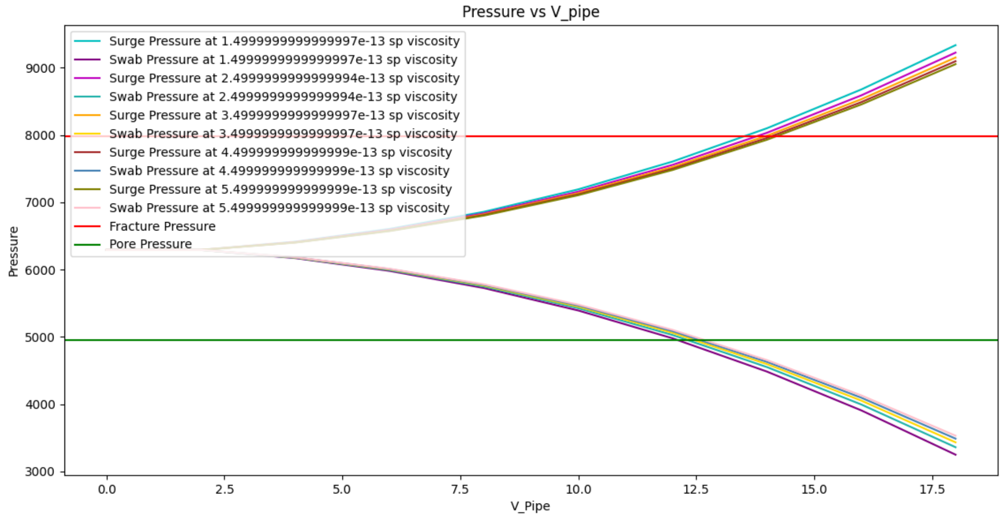

Figure 4-3. Python Output - Changing Viscosity.

4.5. Yield Point

Yield point can be defined as the stress needed to trigger the fluid flow. It is possible to derive the yield point from measure values of viscometer of shear stress and can be expressed in pounds per square foot (lbs/ft2). When it moves, it is a calculation of the electrical forces in the fluid. It is possible to determine the yield point from the dial read from the viscometer, according to Bingham.

$YP = \Theta 300 - PV$ (3-2)

$\Theta 300$ = Dial reading when the viscometer is running at 300 RPM

PV = Plastic Viscosity

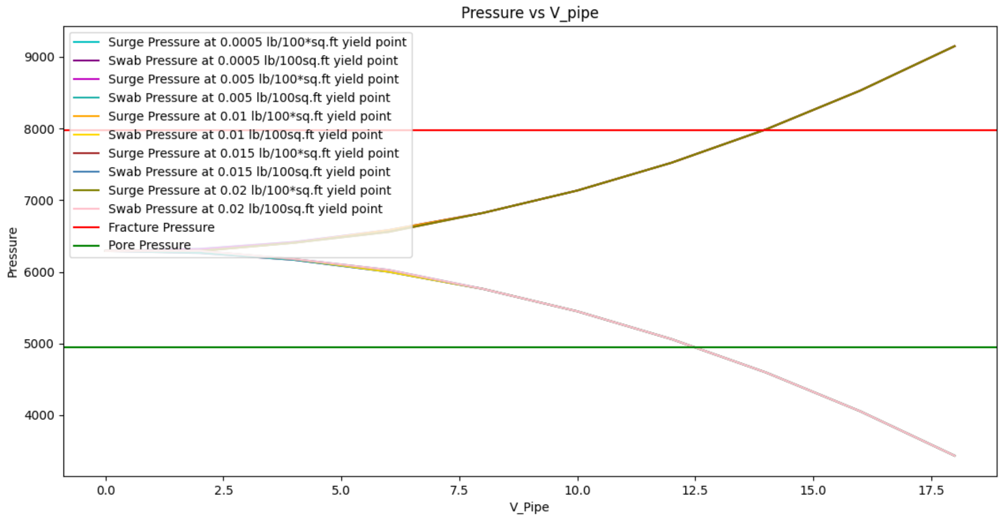

Figure 4-4. Python Output - changing Yield Point.

4.6. The geometry of the wellbore

The clearance between the borehole and the drill string is very essential, the lower the clearance, the more fluid flow must overcome by restriction. The swab & surge pressure goes up when the annular clearance is reduced that it is influenced by a lot of factors such as doglegs, hole angle, BHA volume, balling, stabilizer numbers and swelling formations. Depending on the annular eccentricity and diameter ratio, the speed of tripping varies. The large hole size enables drilling mud to fill quickly while tripping out of the hole in the position which was occupied by the drill string. It is then easy to monitor pore pressure formation, and blowouts are prevented. The mud can be provided with a wider passage area by a wide hole when tripping in.

The piston-cylinder movement acting counter to the formation is reduced and it is possible to prevent fracturing of the formation in inclined and horizontal wells, eccentricity mainly affects the surge and swab pressure. The pipe can be moved more easily than expected by concentric models and can still function safely. This is because the loss of differential pressure in a concentric annulus is greater than in an eccentric annulus. The section at the end of the drilling string is the bottom hole assembly (hereinafter referred to as BHA). The drill bit is at the bottom of the BHA. A drill collar, stabilizer, reamer, heavyweight drill pipe, jarring unit, mud engine, directional drilling equipment, MWD, and logging tools may also be used. The functions of the BHA components are to penetrate the formation, stabilize the drilling, improve directional control, and optimize the efficiency of the drilling. Most of the pressure loss in the well is shown to occur around the BHA, especially where the annular space is limited.

The bottom hole assembly (abbreviated as BHA) is the component at the drill string's

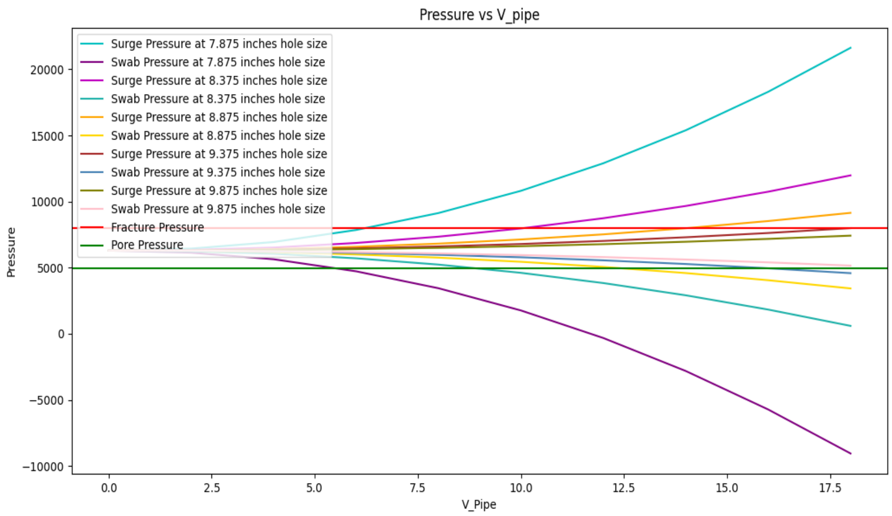

Figure 4-5. Python Output - changing Hole size.

end. The drill bit is located at the bottom of the BHA. A drill collar, stabilizer, reamer, heavy weight drill pipe (HWDP), jarring device, mud motor, directional drilling equipment, MWD, and logging instruments may also be included. The objectives of the BHA components are to penetrate the formation, stabilize the drilling, improve directional control, and increase drilling performance and effectiveness. Below is an explanation of the BHA's various components. The majority of well pressure loss occurs around the BHA, especially where the annular space is limited. Most oilfield service providers have technology to model BHA behavior, such as the highest WOB attainable, directional inclinations and capabilities, and even the natural harmonies of the assembly to avoid vibration caused by stimulating natural frequencies, before to running a BHA.

The mud system serves a variety of functions in drilling engineering. It is pumped through the drill string, and out of the bit nozzles, bringing formation cuttings from the bottom hole to the surface through the annulus. The cuttings are washed out 17 in a shaker, and the mud is returned to the mud tank. As a result, the mud's primary function is not the removal of cuttings and the cleaning of the pit. Water, clay, and additives are commonly used in drilling mud. In a drilling operation, the mud system serves several critical functions. It is pumped from the mud pit via the drill string, out through the bit nozzles, and up to the surface through the annular gap, carrying cuttings from the well. The mud then passes through a shaker, in which the cuttings are removed, and the mud is returned to the mud pit.

The various properties of drilling fluid play a critical role in a successful drilling operation and are the most easily adjustable variables of the procedure. Each mud program used to drill a well is adapted to the well's unique characteristics. The drilling fluid measures required by the American Petroleum Institute (API) to characterize the primary features are density, viscosity, and gel strength, filtration, sand concentration, Methylene Blue Capacity, pH, and chemical analysis (Kovalev, M. K., Ren, H., Zakir Muhamad, M., Ager, J. W., & Lapkin, A. A., 2022).

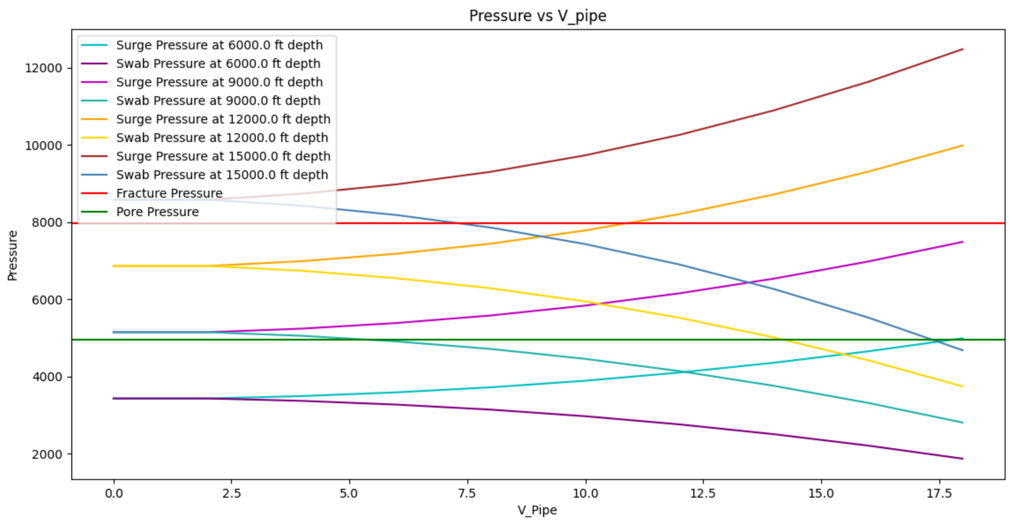

Figure 4-6. Python Output - Changing Depth.

4.7. DWT sensor readings

In the last step, as I have used simulated data, I assumed that sensors of data while tripping tool measures the pressure values for each 500-1000 ft. But it is also important to take friction into account, which is about 0.5-1% of hydrostatic pressure. So, using that information and simulated data, the graphs are obtained for the given depths and swab and surge pressures are recorded. As a result, via that pressure values the pressure and depth relationship are set in the table.

Table 4-1. DWT seonsor readings.

Sensor readings (Tripping in & out)		
TVD	Swab - DWT	Surge - DWT
0	0	0
1000	695	449
2000	1387	904
3000	2080	1348
4000	2778	1803
5000	3466	2254
6000	4167	2704
6500	4514	2930
7000	4870	3164
7500	5209	3380
8000	5546	3606
8500	5860	3820
9000	6233	4060
9500	6562	4269
10000	6951	4513
10500	7270	4724
11000	7631	4940

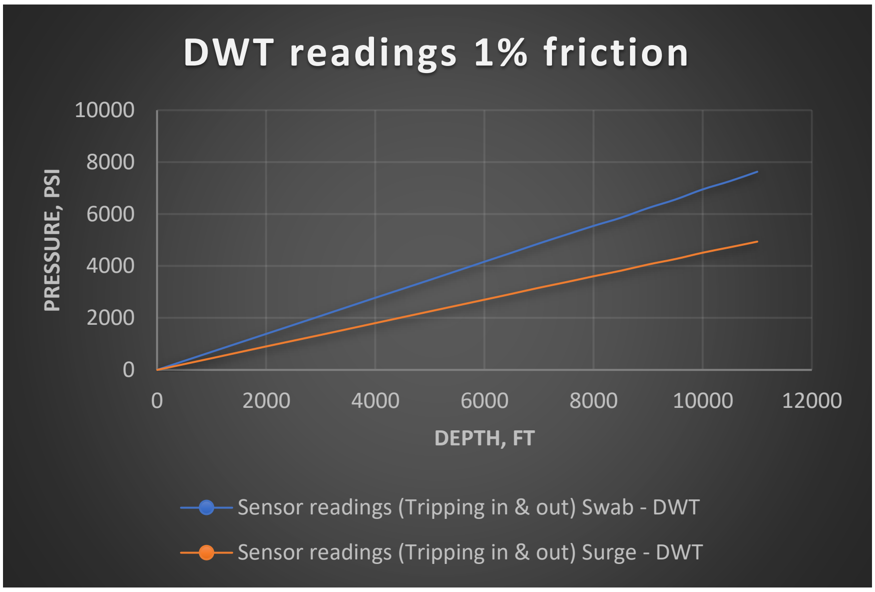

Figure 4-7. DWT sensor readings (1% friction)

5. Problems related to surge and swab

Several experiments have been conducted to investigate the effects of surge and swab pressure. Wellbore difficulties such as lost circulation, formation fracture, kick, wellbore damage, and other wellbore issues were linked to a swab and surge pressures in early study.

When a string is inserted into a hole, the drilling mud is forced out of the well. Similarly, the mud that is right near the drill string is being dragged down. The piston's impact causes a surge pressure that is added to the mud hydrostatic pressure. Additional pressure surge can cause borehole pressure to rise to the point where circulation is lost. When the drill string is pulled out of the wellbore, the fluid flows down the hole to fill the void left behind. This causes a suction force, resulting in a swab pressure that lowers the differential pressure and, most likely, brings formation fluid to the bore hole.

Surge and swab pressure can contribute to dangerous situations. When the swab pressure is too high, the formation pressure can exceed the wellbore pressure, causing a flow into the bore hole. This happens because the swabbed hydrostatic mud column can no longer control the pressure of formation. This is a big concern, as some fluid gain in the borehole can lead to the borehole blowing out. The surge pressure, on the other hand, is subjected to excessive hydrostatic pressure. If the pore formation and fracture pressure margins are thin, any extra pressure, such as surging pressure, is applied to the hydrostatic mud pressure, allowing the formation to be fractured. The mud column within the formation can be lost by fracturing the formation. This lowers the hydrostatic pressure on the formation, allowing the well to flow more freely and causing a substantial well control issue (Al-Abduljabbar, 2018).

5.1. Fluid Influx

There will always be a decrease in bottom hole pressure when removing the drill string out of the well. Friction between the drill string and the drilling fluid causes this reduction in

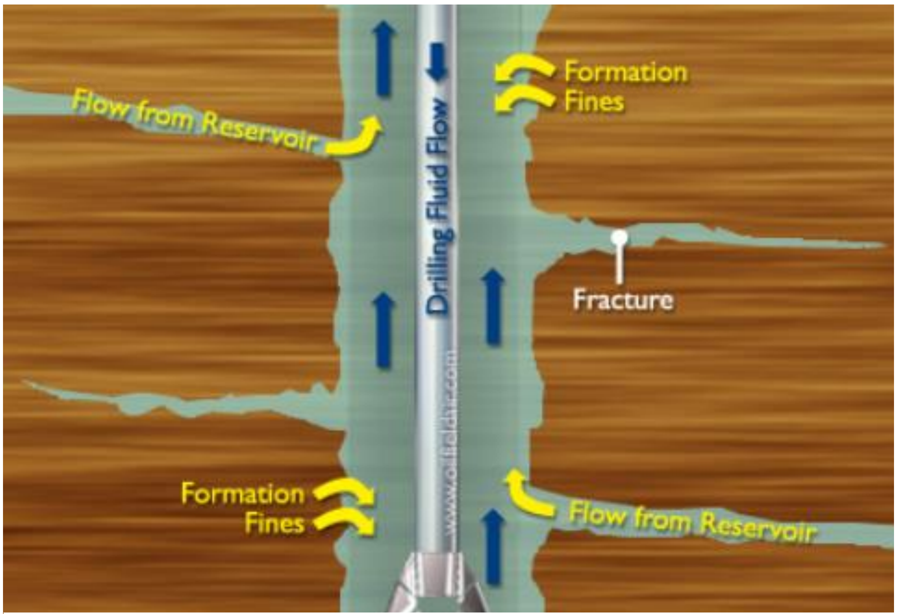

Figure 5-1. Fluid Influx (Effendi, 2011)

pressure. Pulling up the downhole instruments might also cause swabbing (bits, reamers, stabilizers, core barrels, etc.). They can provide a "piston-like" impact when pulled through mud. This type of swabbing can have a big impact on the bottom hole pressure. The formation fluids will enter the well if the pore pressure of the formation exceeds the pressure of the drilling fluid in the borehole. This could be due to swabbing, which causes the pressure to drop as the drill string pulls out of the hole. A kick or a blowout may result from the influx of formation fluid.

5.2. Lost Circulation

One of the most serious issues associated with surge pressure is lost circulation. When the drill string is tripped into the borehole, it creates and exerts pressure on the well's bottom. To depart the volume being entered by the drill string, fluid in the well must flow upward. As a result of the piston effect, the hydrostatic pressure rises, also known as surge pressure. When the surge pressure surpasses the fracture pressure of the formation, it can cause formation fracturing and weakening. Continuous fluid loss into the permeable formation can also result from a high surge pressure, resulting in lost circulation. The mud injected down the well will move into the fractures, reducing the vertical height of the mud columns and reducing the hydrostatic pressure in the wellbore.

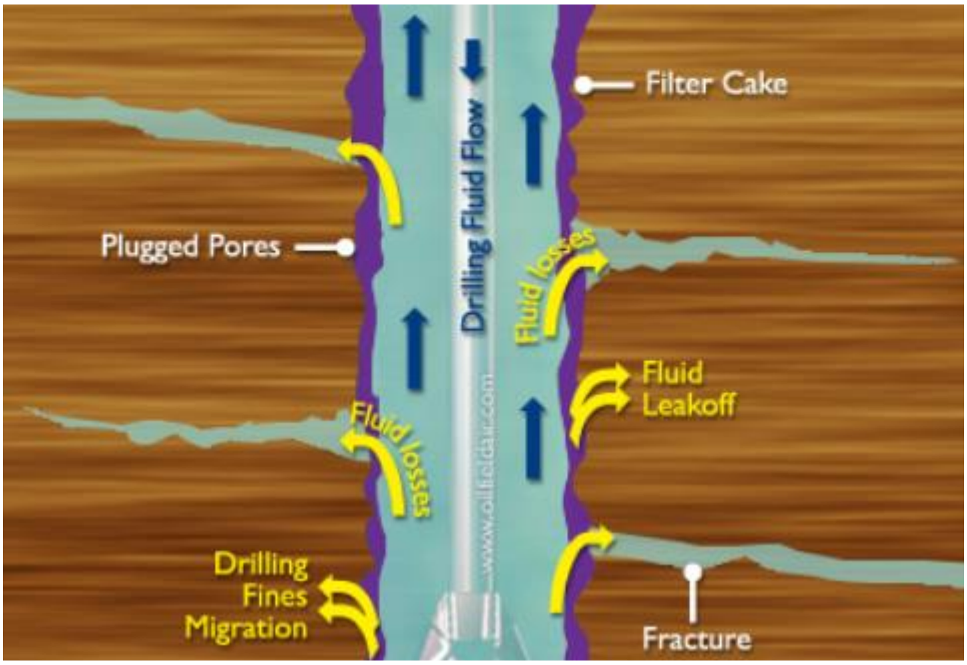

Figure 5-2. Lost Circulation to the formation (Effendi, 2011)

5.3. Kick and Blowout

The result of a fluid influx is a kick. The formation fluid enters the borehole, pushing the drilling fluid out of the wellbore and increasing the mud volume. There are two types of kicks: induced and underbalanced. The kick is unbalanced if the mud weight is insufficient to keep the formation fluids in place. This is typically not a concern in tripping operations unless formation fluid enters the well and the mud weight is insufficient to control the well. The induced kick happens when dynamic or intermittent pressure influences decrease in the well pressure, such as swab pressure. Given the catastrophic consequences, it's critical to keep an eye on the fluid flow and detect kicks. If a kick is seen on the floor, the drillers must take the appropriate measures and destroy the well. This is usually accomplished by circulating the kick out before pumping down mud with an increase density known as kill mud, or by using the kill mud to pump out the kick fluid in a single circulation.

If the proper steps are not performed when the kick occurs, the well may blow out, resulting in an uncontrolled flow of formation fluid. Blowouts are divided into three categories: surface, subsurface, and underground. The most common type of blowout is a surface blowout, in which the pressure of the fluid flowing to the surface is high enough to damage the drilling rig and the surrounding area. Because of the severe environmental implications when formation fluids are mixed with water, the subsurface blowout is the most problematic to deal with. Underground blowouts are rare and happen when fluid flows uncontrollably from high-pressure zones to lower-pressure zones. It can take a very long time to regain control after a blowout, and the danger to human life, ecological and material degradation, and economic losses make preventing a blowout a top concern.

If the downhole pressure varies due to surge and swab influences during the tripping of the drill string, wellbore instability will become a severe problem. Although the borehole pressure was correctly approximated by the geo-mechanical model, incorrect tripping variables may reduce the recommended pressure in order to mechanically maintain the wellbore wall (Alsubaih, Ahmed, Albadran, Firas, Abbood, Nabeel, and Nuhad Alkanaani., 2018).

Because of the pressure of the wellbore across a zone, tensile spalling can occur. If the formation has a low strength or pre-fractured, the inequality between the pore pressure of formation and the wellbore will push loose rock out of the wall. Rapid pore pressure excesses caused by surge pressures can result in a rapid loss of rock strength, which can lead to disaster. Other pore pressure penetration-related phenomena, such as filter cake performance in permeable formations and capillary threshold pressure for oil-based mud, can aid in wellbore stabilization (Pašić, B., Gaurina-međimurec, N., & Matanović, D., 2007).

Borehole instability is characterized as an undesired situation of the open-hole interval where the size and shape of the gauge, as well as its mechanical strength, are not preserved. When drilling unstable formations, wellbore instability issues raise non-productive costs and time.

5.4. Pressure control during drilling

Proper wellbore pressure control is a crucial prerequisite for a safe and responsible drilling operation. To prevent a collapsed borehole and/or an undesired influx of formation fluids, known as a kick, the wellbore pressure must be sufficiently high. Similarly, the pressure in the wellbore should not exceed the formation's maximum pressure tolerance. Fractures will form along the borehole wall, and drilling fluid will be lost to the formation, a condition known as lost circulation. The mud weight window is a plot that depicts the pressure conditions at which these accidents occur. Drilling for hydrocarbons was carried out without any kind of pressure control until the early 1900s. Drilling-related hydrocarbons would flow uncontrollably to the surface, resulting in a blowout. As previously stated, a kick implies to an undesired inflow of formation fluid. If the ability to manage this influx is gone, and hydrocarbons flow at an uncontrolled rate through the surface, the problem has evolved to a much more dangerous situation, namely a blowout. A situation like this could have significant economic ramifications and, in the worst-case scenario, result in the loss of human life. Several blowouts occurred in the early twentieth century as a result of the drilling technique, including the Spindletop blowout on January 10, 1901. On that day, the morning news stated that a substantial stream of petroleum rose two hundred feet (61 meters) into the air from the earth. The Spindletop well leaked up to 100 000 barrels (15 900 m3) per day for 9 days before it was ultimately brought under control (Langley, W. D. and Dunsavage, P. M., 1970).

5.5. Problem with Heaving

In case of pipe slides during the dismantling or reassembly of the subsequent support, the impact compensation at the top of the drill string is turned off. The entire drill pipe begins to go up and get down through the rig. The similar action occurs if casing liners are working or installing finishes.

5.5.1. HEAVING DOWNWARDS

If the pipe, liner, or completion slides down, a rapid increase in pressure of downhole in the well occurs, that can exceed the pressure of fracture and seriously harm the well, disrupting its upcoming efficiency.

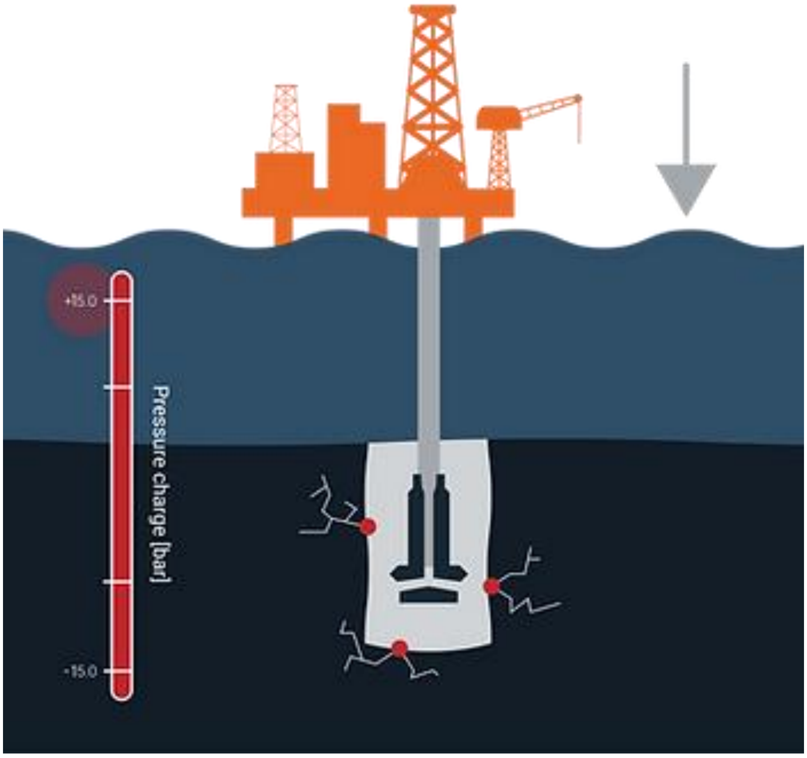

Figure 5-3. Heaving Downwards. (Kvernland, 2019)

5.5.2. HEAVING UPWARDS

If the pipe, liner, or completion goes up, a rapid decrease in pressure of downhole in the well occurs. When the pressure of downhole is getting less than that of pore pressure, hydrocarbon fluids will move to the wellbore. During operation, engineers should maintain the pressure over collapse limit. Otherwise, the part of the well will be harmed.

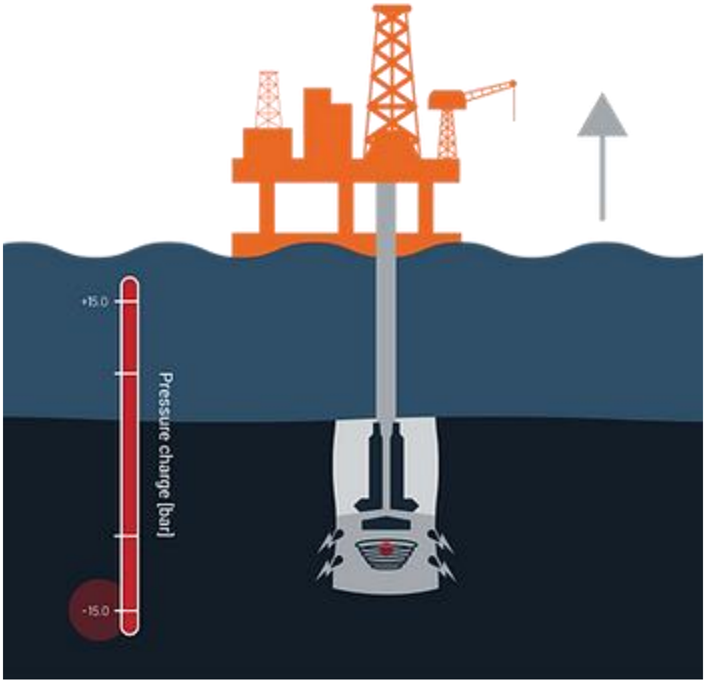

Figure 5-4. Heaving Upwards. (Kvernland, 2019)

5.5.3. SURGES IN ANNULUS FLOW

Surge and swab instigated by rig hurl causes annular stream floods. A few devices in the string like slips are set off by an expansion in annulus stream. Completion may be set rashly

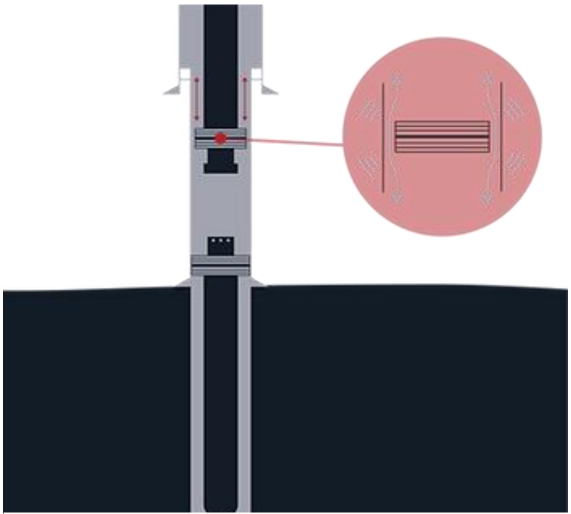

Figure 5-5. Surges in Annular Flow. (Kvernland, 2019)

on the off chance that as far as possible is surpassed, prompting expensive free time. Other downhole instruments may be harmed by unreasonable annulus stream. Heave restriction proposals, given by hardware providers are generally conventional and not customized to your well.

6. Data transmission - Telemetry methods

As indicated above, exceptional downhole devices take directional valuations of the wellbore and petro physical estimations of the characteristics of formation that make it conceivable to comprehend downhole conditions progressively. In any case, these estimations and downhole information should be shipped off the surface through certain method for signal transmission.

A framework for changing over the estimations taken by MWD/LWD instruments into a reasonable structure for transmission to the surface is known as telemetry. A predetermined number of transmission channels are accessible to send information from downhole to surface. Also, there are two kinds of telemetry wired and remote (Mwachaka, 2019).

6.1. Electromagnetic telemetry

Electromagnetic telemetry strategies in petroleum and gas wells include utilizing the drill string to proliferate electromagnetic waves that can be estimated on the world's surface. The EMT framework lays out a two-way correspondences interface between the surface and the device downhole. Utilizing low-recurrence electromagnetic wave spread, the EMT framework works with fast information transmission to and from the surface. Data is gotten at a surface receiving wire, decoded, and afterward handled by a PC. EMT permits information move paces of up to 12 bps-bits each second contingent upon the profundity of the well (Schnitger, 2009).

EMT is a solid telemetry framework (due to the absence of moving parts) yet has constraints on the sorts of wells where it tends to be utilized. It is principally utilized in land apparatuses and shallow wells where great outcomes have been noticed. In any case, it is restricted by profundity, arrangement resistivities, and mud resistivity. The fundamental bottleneck of this innovation is that the development conductivity will adversely affect the electromagnetic engendering profundity and consequently in the information move. Likewise, it is a costly innovation to use in the field.

6.2. Drilling fluids and Mud pulse Telemetry

The mud framework is critical during drilling activities. It fills a wide range of needs, the most focal being the essential hindrance between the wellbore and the surface.

Controlling the hydrostatic tension of a mud section is a basic piece of a drilling activity. The heaviness of the mud adjusts or defeats pore strain in the wellbore. Additionally, the mud weight and the mud properties should be observed and acclimated to remain inside the prerequisites of the drilling activity. A convergence of liquids from the development, otherwise called a kick, is forestalled by having adequate hydrostatic tension or mud weight. Be that as it may, unnecessary strain should be kept away from as it can make water powered cracks in the development, which prompts loss of dissemination into the arrangement. Moreover, the mud being siphoned cools and greases up the bore, and afterward it streams upwards to the surface, through the annulus, shipping the eliminated arrangement or cuttings from the wellbore (Hutin, R., Tennent, R. W., & Kashikar, S. V., 2001).

Mud Pulse Telemetry (MPT) utilizes the drilling mud framework to send LWD/MWD information gained downhole to the surface. Downhole information is communicated to the surface through the mud section as strain waves. The information is encoded by the device inside the tension varieties or heartbeats in the mud stream. Then, these strain varieties are decoded at the surface by the surface hardware. Three unique ways to deal with make pressure vacillations are depicted by beneath:

6.2.1. Positive pulse telemetry

These are the most well-known sort of mud beat telemetry frameworks. It lessens the flow region of the mud by briefly making a stream limitation downhole, which brings about a positive pulse of pressure that will spread to the surface.

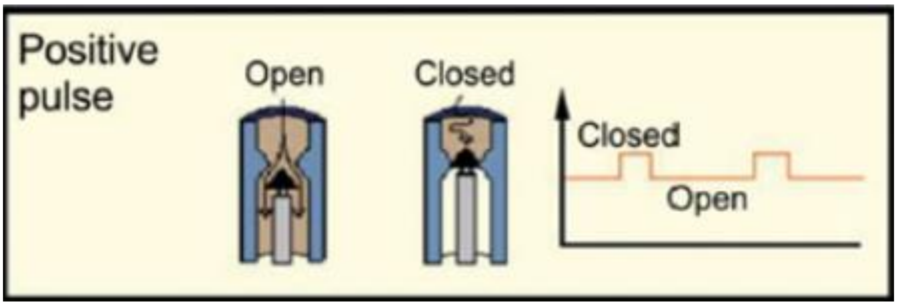

Figure 6-1. Representation of a positive mud-pulse system (Cooper & Santos, 2015)

6.2.2. Continuous-wave telemetry

Those systems have an engine and a stator to produce pressure fluctuations. By changing the place of the motor, the drilling liquids will either have a smoother stream-

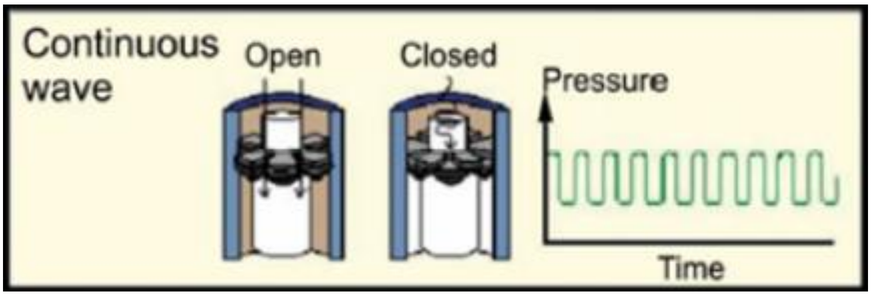

Figure 6-2. Representation of Continuous mud-pulse system (Cooper & Santos, 2015)

expanded opening or a more restricted-decreased opening stream. Persistent opening and shutting of the motor will cause consistent tension motions.

6.2.3. Annular-venting telemetry

A release valve opens and closes, inciting drilling fluid from the drill string going through the annulus. That can make pressure instabilities inside the mud fragment, which are

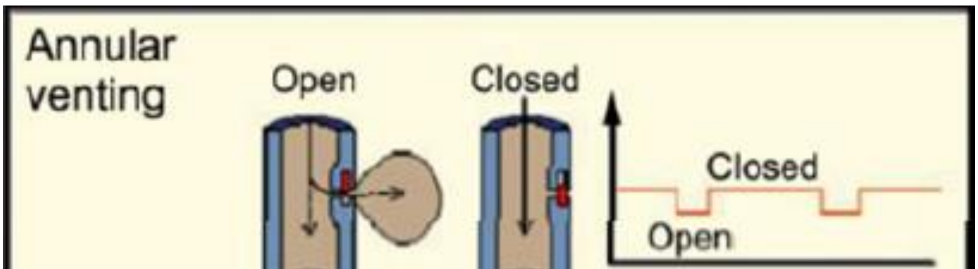

Figure 6-3. Representation of negative mud-pulse system (Cooper & Santos, 2015)

known as unfortunate pulses. These will send the instrument's encoded data to the surface and will be decoded by the surface offices.

The importance of mud pulse transmission in the petroleum and gas industry is acknowledged. This technique is commonly used to transmit data from multiple well tools and is very cost-effective for most applications. Besides being used in the drilling industry, MPT is also widely used in other fields due to its proven performance.

The economic benefits of using the mud column as an MPT transmission channel are numerous. Aside from being economical, this method also eliminates the need for special equipment. Over the years, various technological advancements have been made to improve the system's performance (Cooper, P., & Santos, L. S., 2015).

New sophisticated algorithms are used to improve the system's performance. These new features have allowed it to perform better and increase its reliability.

Various arrangements have been created by oil field specialist organizations to accommodate the varying requirements of their customers. These include the design and implementation of multiple MPT solutions, as well as the development of new LWD and MWD programs. Most of the time, these procedures are carried out by small and medium-sized undertakings that require minimal information move times.

Projects that require more sophisticated MWD and LWD devices will require faster information move times. Some of the specialist organizations that can provide these services include those that develop fast telemetry frameworks. These allow them to provide a data move rate of up to 10 pieces per second.

Rapid drilling at sea is costly for upgrade drilling tasks and provides an unmistakable economic reason for choosing an unquestionably professional solution. It saves cash by reducing high penetration costs.

In any case, the presentation of very high-quality new L / MWD advances has led to the expansion of information content. Th e current business information telemetry proposed by the MPT limits the use of the vast amount of well information accessible by existing L / MWD equipment.

The presentation of these new devices required larger transmission capacities and faster information transmission speeds.

In addition, drilling innovations and improvements in drilling technology have increased penetration (ROP) and required faster continuous information speeds to accommodate larger log thicknesses. Similarly, to the eight deeper wells require the use of exceptional types of osmotic fluids that affect the boundaries of information movement.

The actual properties of the fluid, such as thickness, temperature, and plasticity consistency, make encoding mud pressure surges an undeniably difficult task. These problems observed with the MPT are very large, but at the moment, a slightly newer telemetry framework overcomes them, which is wire pipe telemetry. Innovation Wired Drill Pipe (WDP) was developed and financially announced in 2006.

7. Challenges of WDP and future improvements and opportunities

WDP has come across plenty of challenges during a long way since its entry to the market. Advantages of WDP have been manifested on the drilling process which are high speed and high-quality real-time data acquisition. Nevertheless, there are some difficulties when WDP is utilized as telemetry method in the drilling process. These challenges usually include reliability, handling procedures, operational cost of the technology and a lot of data whose positive impacts are doubted (Edwards, S. T., Coley, C. J., Whitley, N. A., Keck, R. G., Ramnath, V., Foster, T., ... & Honey, M., 2013).

7.1. Reliability

Reliability is the probability that the system will perform its function adequately as it is predicted. The WDP system comprises several components linked in series. A series system is that all components comprising the system should operate in sequence for the system to be able to run.

Figure 7-1. Reliability of a system in series (Ruysschaert, Z., & Gabriel, W., 2021)

At the moment, WDP is operating its second-generation design where a lot of failures are observed which were also came across in the first design. Inductive coil and armored cable passing through the pipe has been improved in terms of designation and placement. In order to prevent cracking because of stress corrosion, stainless steel armored cable was altered to the Inconel material. Intellicoil was re-arranged in the way that it was placed on the internal diameter of pin connection by being recessed and fixed. These changes in the design upgraded reliability and raised repairability (Sehsah, O., Ghazzawi, A., Vie, G. J., Al-Tajar, T., Ali, A., Al-Mohammed, A. H., ... & Balka, M., 2017).

However, increased utilization of the equipment has negative impacts on the durability of the parts of WDP system. Therefore, the process requires adequate management of the drill string which includes constant rotation of equipment in order to change the utilization of components and demobilization of equipment after approximately 750 hours of use (Schils, S., Teelken, R., van Burkleo, B., Rossa, O. J., & Edwards, N., 2016).

It is very important to provide each WDP part to function properly. All components have to operate at the same time, because failure in one component will lead to shut down on the whole WDP system depending on the failure point. For instance, if problem occurs in the part of equipment placed in the middle of drill string, the signal will not be able tof travel to the end point and will stop in the middle. Therefore, it requires to inspect components of WDP system regularly while they are tripped in the hole.

Introduction of DWT system gave the opportunity for inspecting all the parts of the

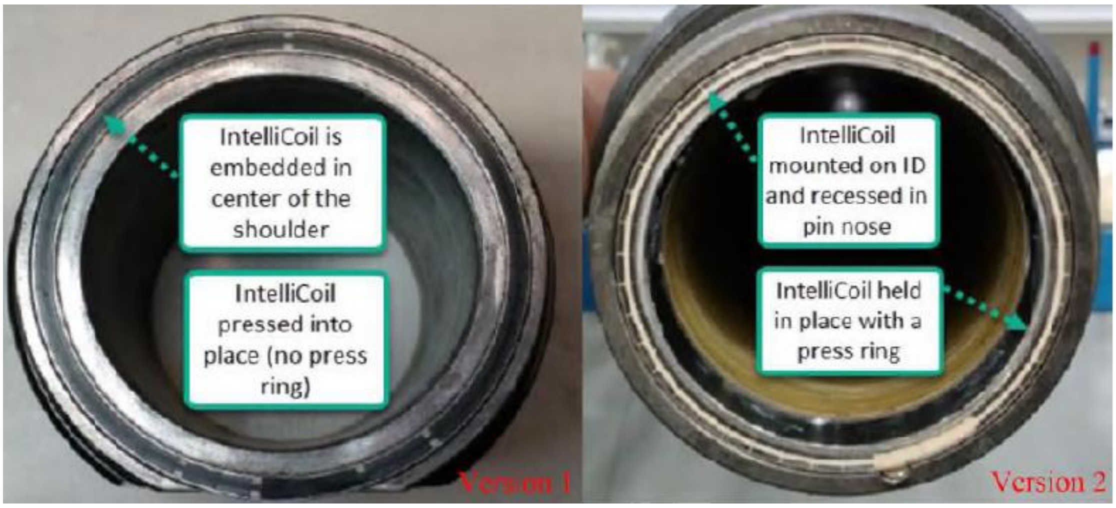

Figure 7-2. Left: Intellicoil's first generation. Right: Intellicoil's second-generation (Sehsah et al., 2017)

wired string, enabling early detection of problematic components and replacement of them in time. On the other hand, removal of faulty parts during running in hole processes brings about increase in non-productive time in the project. Another problematic case is that if the component placed in the downhole fails, it will be very complicated to substitute that part. If this case happens during drilling operation, usually drilling section is finished by drillers by shifting to mud-pulse telemetry because a pulser constitutes a component of every MWD system.

Now, running WDP will be accounted as primary telemetry and the pulser as backup. This condition enables for drilling operators to improve the reliability of the telemetry system. It results in excess in the system to possess both canals ready to be operated upgrading its performance. A breakdown in the pulsing equipment during regular operations with just MPT results in unscheduled trips out of the hole to substitute the damaged equipment, resulting in costly non-productive time. Straightforward shift from WDP to MPT provides availability of a communication channel.

7.2. Handling and caring

It is needed to manage WDP system with special care. There are several adequate pipe handling practices in this case. Firstly, connections of the drill string should be kept clean, secondly connections must be made up by using good and even amounts of thread compound, thirdly proper torque should be applied in order to prevent deformation and deterioration of the internal parts of equipment while cautious stabbing of the connections is achieved. If the drilling contractor follows and complies these practices mentioned above, it positively impacts on its key performance indicators. Avoiding complying these requirements could raise the probability of WDP parts to get damage which can result in failure of the whole system.

7.3. Cost of investment

Investment cost of WDP technology comprises significant amount of money although data of precise figures for installing WDP system is not easily available because this information is secret of the company. Also, capital and operational cost of the system has dependency on the material and amount of pipes, tools utilized and project's scale. On the other hand, according to (Schils, S., Teelken, R., van Burkleo, B., Rossa, O. J., & Edwards, N., 2016), Information regarding with investment cost of WDP system installed in Martin Linge offshore field is provided which gives opportunity to analyze advantages of the system. It was defined that capital cost of the technology would break even, but plenty of other advantages were identified during the progress of the project.

Drilling operation on the offshore is one of the costliest single projects all around the world that approximately 450000 USD is spent for hiring the drill rig while the duration of operation is expected to be between 30 and 70 days for completion of the drilling activity (Gielen, D., & Bazilian, M. D., 2021). By analyzing these figures, we can easily say that even saving the very short time can have significant benefits in terms of decreasing the costs. The major purpose of applying WDP and ASM technology on the Martin Linge project was that the reservoir had complex structure and severe conditions which would lead to a lot of instabilities on the well and well control difficulties. Hence, successful drilling operation could only be achieved by fully comprehending the reservoir conditions (Schils, 2016). The damage on downhole tools was prevented by applying drilling dynamics management leading to prevention of undesirable TOH for replacing the equipment. Real time data transfer allowed operators to take actions in time by increasing decision making efficiency during the critical processes like well stability problems. ASMs supplied vital ECD data during drilling process which helped to get ideal well cleanliness and decreased hole cleaning time (Schils, 2016).

7.4. Large amount of data

The question of what amount of data a person can process at maximum is answered by Equinor’s study. According to this, not many people have the mental energy and capability to keep full attention at all times while analyzing the potential results and a great number of monotonous tasks. Therefore, with these limitations arising from being a human, drilling takes more time than what is actually possible (Gielen, D., & Bazilian, M. D., 2021). So, it can be said that the amount of data should be processed as soon as possible and accurately in order to avoid a risk arising from hoard of data. The road to do this pass from having nonstop improvement of visualization software and from each discipline in the drilling process to work collaboratively.

7.5. Future opportunities- digitalization and automated drilling

The quick and great growth of technology significantly draw attention to topics such as what digital data is, how it could be used and utilized and what these data can offer. Knowledge about such topics can be handy for evolution of automated drilling. Automation of drilling has a chance to result in less employees physically who are under several risks that might occur during the drilling tasks. Therefore, automation of drilling could result in safer operation processes. Automation also can improve the efficiency of the processes overall resulting in less operation costs. The foundation of Remote Operation Centers (ROC) happened because a good number of operators and service providers decided to shift the way they operate from physical to remote (Gielen, D., & Bazilian, M. D., 2021). On the other hand, Remote Operation Centers and digitalized drilling strictly requires having the related data available at the time. WDP system is able to transfer vast amount of data from surface to downhole equipment and vice versa which gives great opportunity for more advanced automation because of having possibility to close the loop. Collaborative digital environment can be achieved by improving automotive infrastructure and systems. The digital environment allows the operation control to take place anywhere and anytime which ultimately benefits the cooperation of each party who is in the drilling process by crushing the limits of geography. Remote monitoring results in less employees physically who are under risks when exposed to wellsite red zones. So, the benefits arising from usage of high quality and real time data from WDP are worthy of note. Ability to deliver all data derived from L/MWD devices in real time to more advanced technologies will give opportunity to have more accurate and precise levels. Up-to-date infrastructure and intelligent networks were developed by the main drilling service companies where optimization of downhole observation and drilling control is achieved with the help of application of artificial intelligence, machine learning and other complicated algorithm techniques. The application of WDP high-speed data transfer of downhole sensors (ASMs, L/MWD, and RSSs) integrated to machine learning and artificial intelligence allows the industry to get full benefits of the improvements of the modern automotive technologies. The services mentioned uses the whole data coming from the downhole tools and do the following activities repeatedly.

- They lower the risk of the bit colliding with wells around by keeping the well trajectory updated by using lots of well projections.
- Precisely steer to the target by using predictive steering which optimizes well placement.
- Improve ROP and increase the life of the bit by using data-driven tendency analysis which spots any change in the downhole dynamics and the surroundings.

Keeping the pressure within a safe spectrum by using optimal annular pressure management system which is able to adjust surface parameters. This way, well control is avoided.

Figure 7-3. Halliburton's LOGIXTM automated drilling service dashboard (Halliburton, 2021a)

8. Health, Safety and Environment

The most hazardous and risky industry in the world is oil industry. The major activities of this sector are drilling, construction, production, maintenance etc. The first and most important concern is assuring safety of human beings, environment as well as plant. As discussed through the report, one of the main advantages of new DWT tool is minimizing the risk for the staff, because they can regulate almost every aspect in control room without being I red zone.

Due to such operations, generation of emissions are solid wastes are possible. In most cases, the emissions include nitrogen oxides (NO_x), sulfur oxides (SO_x), hydrogen sulfide (H_2S) and carbon oxides (CO and CO_2). (Reis, 1996) In modern era, petroleum industry has been searching for the techniques in order to minimize the toxic gas emissions and protect environment. To some extent, they are successful, but it is also undeniable that emissions and pollutions are inevitable during petroleum related operations. Every second in oil and gas industry means toxic emission or pollution. In this report, the method for evaluating the highest value for tripping speed discussed. However, the next challenge is to define the lowest limit for pipe running speed. So, it is true that the low tripping speed causes rise in rig operation time and therefore expenses. In that purpose, we do not have to think about only finance, but also ecology. When thinking about lowest limit of trip speed, you realize that ecology and finance are somehow friends. While thinking about all these factors, it appears that, it is very important to reduce rig time and increase running speed in order to avoid polluting environment.

9. Discussion

As it is discovered in the report, the window for tripping speed is found out via pore and fracture pressure values. In addition, non-productive time is very important in that purpose as well. The equations that are very important to define the dependence between pressure and tripping speed are represented in the “Formulas”. By using these equations, it is much easier to determine the slope of pressure versus pipe speed. From the “Figure 3-1”, it is clearly seen that the highest and lowest limits for pipe speed are obtained. Python coding that are utilized in the whole calculations are given in “Python coding”.

Since DWT is not that popular in all the companies, we can hardly find real field data to use in coding. So, the best option is to have simulated data. According to the simulated data in **Feil! Fant ikke referansekilden.**, the maximum and minimum speed for pipe running operation are 14,05 ft/sec and 12,48 ft/sec. However, it is possible to change these peaks by playing with other factors such as mud weight, viscosity, as well as yield point. The graphs are also given in the report, which depicts how these factors affect the running speed window. What is more, the tripping speed should be selected as much as possible, but lower than fracture pressure, because of NPT.

When thinking about drilling operations, it is very crucial to concern about safety, sustainability, and environment. As it is mentioned, petroleum industry gives lots of pollution and harm to the environment. That is why, decreasing non-productive time is needed. Additionally, one of the most important benefits of DWT tool is reducing the need for personnel in the red zone. As it is clear from the calculations, via software, it is not difficult to have control over tripping operations. By the way, problems related to swab and surge pressure as well as data transmission methods are discussed in the report.

As Data While Tripping technology is very new in the industry, it needs some improvement. The programming of pipe running speed can be done in much more advanced way. In this case, we need to take into account friction factor and real field data is necessary.

10. Conclusion

To sum up, invention of DWT tool is considered as a great success in oil and gas industry. For many years, the industry was dealing with time constraints and environment and safety of personnel. It is obvious that it is not easy to have control overall. However, via DWT equipment, such difficulties can be certainly under control.

The main features and benefits of Data While Tripping device over traditional data transmission method are intended in this report. Up to now, in the oil sector, companies have lost so much rig time during tripping operations. It is because, it was completely impossible to measure and transfer borehole data to the surface while running pipe or string. So, to obtain data, they had to wait for completing tripping. However, by invention of DWT device together with wired drill pipe and along string sensors, data transmission got much easier. Even via such technology, the frequency of data transfer got boosted significantly.

The next concern about tripping operations in oil industry was about human safety. Thus, while tripping, there had to be human that can detect any issue with the wired pipe and screw the pipes and control the connections via cables. But, when using DWT device, the need for personnel in “red zone” is reduced considerably. In this case, the device and operation can be easily activated from the rig floor.

The outputs from Python coding help the reader to understand the main point on the relationship between tripping speed and pressure. Moreover, in the report, the factors that must be considered before the tripping operations are also discussed and depicted via the graphs from the coding.

Apart from the advantages of DWT device, managing tripping speed must be taken into account as well. As discussed in the report, the tripping speed should be maintained in the calculated pressure window. The highest rate for pressure is figure out according to the fracture and pore pressure, while the lowest value is set due to ecological and financial aspects.

When using wired drill pipe, it's necessary to test the sting while tripping. This test is performed automatically when the system activates at each stand when utilizing DWT. There is no need for an extra person on the rig floor, and time is saved because each stand does not need to be tested. This automates the WDP's health, tool connections, and battery life tests.

The tool created is one of the most important pieces in a complicated puzzle to accomplish full automation based on real-time downhole measurements during all phases of well building where drill pipe is used. During tripping operations, this additional data source allows software applications to visualize, regulate, and check modeled data. The continued development of process control interfaces to the rig's control system, which allow a broader range of operations to be scheduled, including dynamic scheduling, opens up new opportunities for application developers to use this new data in innovative ways, resulting in safe and efficient well construction.

All in all, data while tripping technology shows a big step forward towards automation in drilling operations. There can be a potential for introduction of fully automated drilling services if machine learning and artificial intelligence is developed with combination of WDP technology in the future.

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12. Apendix

12.1. Formulas

DRILL PIPE (Pressure drop)

$$V_{critical} = \frac{1.08\mu_p + 1.08\sqrt{\mu_p^2 + 9.3\rho(D_{hole} - OD_{DP})^2 YP}}{\rho(D_{hole} - OD_{DP})}$$

$$V_{average} = V_{pipe} * \left(\frac{1}{2} + \frac{OD_{DP}^2}{D_{hole}^2 - OD_{DP}^2}\right)$$

$V_{average} > V_{critical}$ → Turbulent flow

$V_{average} < V_{critical}$ → Laminar flow

$$\Delta P_{laminar} = \frac{L}{300(D_{hole} - OD_{DP})}\left(YP + \frac{\mu_p V_{average}}{5(D_{hole} - OD_{DP})}\right)$$

$$R_e = \frac{2790\rho V_{average}(D_{hole} - OD_{DP})}{\mu_p}$$

$$f = e^{\left(C1 + \frac{C2}{R_e}\right)} + C3 * \ln(R_e)$$

$$C1 = -3.5378591164$$

$$C2 = 300.26609292$$

$$C3 = -0.126153971$$

$$\Delta P_{turbulent} = \frac{fL\rho V_{average}^2}{25.8(D_{hole} - OD_{DP})}$$

$$\Delta P = \Delta P_{dp} + \Delta P_{dc}$$

$$P_{surge} = P_{hydrostatic} + \Delta P$$

$$P_{swab} = P_{hydrostatic} - \Delta P$$

DRILL COLLAR (Pressure drop)

$$V_{critical} = \frac{1.08\mu_p + 1.08\sqrt{\mu_p^2 + 9.3\rho(D_{hole} - OD_{DC})^2 YP}}{\rho(D_{hole} - OD_{DC})}$$

$$V_{average} = V_{pipe} * \left(\frac{1}{2} + \frac{OD_{DC}^2}{D_{hole}^2 - OD_{DC}^2}\right)$$

$V_{average} > V_{critical}$ → Turbulent flow

$V_{average} < V_{critical}$ → Laminar flow

$$\Delta P_{laminar} = \frac{L}{300(D_{hole} - OD_{DC})}\left(YP + \frac{\mu_p V_{average}}{5(D_{hole} - OD_{DC})}\right)$$

$$R_e = \frac{2790\rho V_{average}(D_{hole} - OD_{DC})}{\mu_p}$$

$$f = e^{\left(C1 + \frac{C2}{R_e}\right)} + C3 * \ln(R_e)$$

$$C1 = -3.5378591164$$

$$C2 = 300.26609292$$

$$C3 = -0.126153971$$

$$\Delta P_{turbulent} = \frac{fL\rho V_{average}^2}{25.8(D_{hole} - OD_{DC})}$$

$$\Delta P = \Delta P_{dp} + \Delta P_{dc}$$

$$P_{surge} = P_{hydrostatic} + \Delta P$$

$$P_{swab} = P_{hydrostatic} - \Delta P$$

12.2. Python coding

```
import math

import numpy as np

import matplotlib.pyplot as plt


def V_critical (mu_p, rho, D_hole, OD, Y):

    return (1.08 * mu_p + 1.08 * math.sqrt(mu_p**2 + 9.3*rho*(D_hole - OD)**2*Y)) / (rho * (D_hole - OD))


def V_average (V_pipe, D_hole, OD):

    return V_pipe * (0.5 + OD**2 / (D_hole**2 - OD**2))


def find_Re (rho, V_ave, D_hole, OD, mu_p):

    return rho * V_ave * (D_hole - OD) / mu_p


def find_f (C1, C2, C3, Re):

    return math.exp(C1 + C2/Re) + C3*math.log(Re)


def pressure_hydro  (rho, L):

    return rho * L


def pressure_laminar (L, D_hole, OD, Y, mu_p, V_ave):

    return L * (Y + mu_p * V_ave / (5 * (D_hole - OD))) / (300 * (D_hole - OD)) / 1000


def pressure_turbulent (f, L, rho, V_ave, D_hole, OD):

    return f * L * rho * V_ave ** 2 / (25.8 * (D_hole - OD)) / 1000
```

```
def pressure_fracture ():

    p_overburden = 0.96

    p_frac = 0.67

    poisson_rate = 0.25

    L = 11000

    return 7.5 * (p_overburden - p_frac) * L * (poisson_rate / (1 -
poisson_rate))


def pressure_pore():

    p_pore = 0.45

    L = 11000

    return p_pore * L


def pressure_surge_and_swab(V_pipe):

    rho = 0.572

    mu_p = 0.00000507632103

    D_hole = 0.73958333

    Y = 1

    L = 11000

    OD_dp = 0.375

    OD_dc = 0.5625

    C1 = -3.5378591164

    C2 = 300.26609292

    C3 = -0.126153971


    V_critical_dp = V_critical(mu_p=mu_p, rho=rho, D_hole=D_hole, OD=OD_dp,
Y=Y)

    V_average_dp = V_average(V_pipe=V_pipe, D_hole=D_hole, OD=OD_dp)
```

```
    Re_dp = find_Re(rho=rho, V_ave=V_average_dp, D_hole=D_hole, OD=OD_dp, 
mu_p=mu_p)

    f_dp = find_f(C1, C2, C3, Re_dp)


    if V_average_dp > V_critical_dp:

        P_delta_dp = pressure_turbulent(f=f_dp, L=L, rho=rho, 
V_ave=V_average_dp, D_hole=D_hole, OD=OD_dp)

    elif V_average_dp < V_critical_dp:

        P_delta_dp = pressure_laminar(L=L, D_hole=D_hole, OD=OD_dp, Y=Y, 
mu_p=mu_p, V_ave=V_average_dp)


    V_critical_dc = V_critical(mu_p=mu_p, rho=rho, D_hole=D_hole, OD=OD_dc, 
Y=Y)

    V_average_dc = V_average(V_pipe=V_pipe, D_hole=D_hole, OD=OD_dc)

    Re_dc = find_Re(rho=rho, V_ave=V_average_dc, D_hole=D_hole, OD=OD_dc, 
mu_p=mu_p)

    f_dc = find_f(C1, C2, C3, Re_dc)


    if V_average_dc > V_critical_dc:

        P_delta_dc = pressure_turbulent(f=f_dc, L=L, rho=rho, 
V_ave=V_average_dc, D_hole=D_hole, OD=OD_dc)

    elif V_average_dp < V_critical_dp:

        P_delta_dc = pressure_laminar(L=L, D_hole=D_hole, OD=OD_dc, Y=Y, 
mu_p=mu_p, V_ave=V_average_dc)


    P_hydro = pressure_hydro(rho=rho, L=L)

    P_surge = P_hydro + P_delta_dp + P_delta_dc

    P_swab = P_hydro - (P_delta_dp + P_delta_dc)


    return P_surge, P_swab
```

```python
if __name__ == '__main__':
    V_pipe_values = np.linspace(0.001, 17.999, 10)

    P_frac = pressure_fracture()
    P_pore = pressure_pore()

    results = [pressure_surge_and_swab(V_pipe) for V_pipe in V_pipe_values]
    P_surge_values = [result[0] for result in results]
    P_swab_values = [result[1] for result in results]

    fig, axes = plt.subplots(figsize=(8, 6))
    axes.set_title('Pressure vs V_pipe')
    axes.set_xlabel('V_Pipe')
    axes.set_ylabel('Pressure')

    axes.axhline(y=P_frac, c='r', label='Fracture Pressure')
    axes.axhline(y=P_pore, c='g', label='Pore Pressure')

    axes.plot(V_pipe_values, P_surge_values, c='b', label='Surge Pressure')
    axes.plot(V_pipe_values, P_swab_values, c='y', label='Swab Pressure')

    axes.legend()
    plt.show()
```

12.3.Python Coding including varying factors

```
if __name__ == '__main__':

    V_pipe_values = np.linspace(0.001, 17.999, 10)


    P_frac = pressure_fracture()

    P_pore = pressure_pore()


    fig, axes = plt.subplots(figsize=(8, 6))

    axes.set_title('Pressure vs V_pipe')

    axes.set_xlabel('V_Pipe')

    axes.set_ylabel('Pressure')


    # Case 1 - changing mud weight: rho

    rho_values = np.linspace(8.5, 12.5, 5) * 0.052

    surge_colors = ['c', 'm', 'orange', 'brown', 'olive']

    swab_colors = ['purple', 'lightseagreen', 'gold', 'steelblue', 'pink']

    for i, rho in enumerate(rho_values):

        results = [pressure_surge_and_swab(V_pipe=V_pipe, rho=rho) for
V_pipe in V_pipe_values]

        P_surge_values = [result[0] for result in results]

        P_swab_values = [result[1] for result in results]

        axes.plot(V_pipe_values, P_surge_values, c=surge_colors[i],
label=f'DWT Surge Pressure at {rho/0.052:.3f} ppg weight')

        axes.plot(V_pipe_values, P_swab_values, c=swab_colors[i],
label=f'DWT Swab Pressure at {rho/0.052:.3f} ppg weight')


    """

    # Case 2 - changing viscosity - mu_p

    mu_p_values = np.linspace(15, 55, 5) * 1.450377437 * 10**(-7)
```

```
    surge_colors = ['c', 'm', 'orange', 'brown', 'olive']

    swab_colors = ['purple', 'lightseagreen', 'gold', 'steelblue', 'pink']

    for i, mu_p in enumerate(mu_p_values):

        results = [pressure_surge_and_swab(V_pipe=V_pipe, mu_p=mu_p) for
V_pipe in V_pipe_values]

        P_surge_values = [result[0] for result in results]

        P_swab_values = [result[1] for result in results]

        axes.plot(V_pipe_values, P_surge_values, c=surge_colors[i],
label=f'Surge Pressure at {mu_p/1.450377437 * 10**(-7)} sp viscosity')

        axes.plot(V_pipe_values, P_swab_values, c=swab_colors[i],
label=f'Swab Pressure at {mu_p/1.450377437 * 10**(-7)} sp viscosity')


    """


    """

    # Case 3 - changing mud yield point:

    Y_values = np.array([5, 50, 100, 150, 200]) / 100

    surge_colors = ['c', 'm', 'orange', 'brown', 'olive']

    swab_colors = ['purple', 'lightseagreen', 'gold', 'steelblue', 'pink']

    for i, Y in enumerate(Y_values):

        results = [pressure_surge_and_swab(V_pipe=V_pipe, Y=Y) for V_pipe
in V_pipe_values]

        P_surge_values = [result[0] for result in results]

        P_swab_values = [result[1] for result in results]

        axes.plot(V_pipe_values, P_surge_values, c=surge_colors[i],
label=f'Surge Pressure at {Y/100} lb/100*sq.ft yield point')

        axes.plot(V_pipe_values, P_swab_values, c=swab_colors[i],
label=f'Swab Pressure at {Y/100} lb/100sq.ft yield point')

    """
```

```
    """
    # Case 4 - changing well depth: L
    L_values = np.linspace(6000, 15000, 4)
    surge_colors = ['c', 'm', 'orange', 'brown']
    swab_colors = ['purple', 'lightseagreen', 'gold', 'steelblue']
    for i, L in enumerate(L_values):
        results = [pressure_surge_and_swab(V_pipe=V_pipe, L=L) for V_pipe
in V_pipe_values]
        P_surge_values = [result[0] for result in results]
        P_swab_values = [result[1] for result in results]
        axes.plot(V_pipe_values, P_surge_values, c=surge_colors[i],
label=f'Surge Pressure at {L} ft depth')
        axes.plot(V_pipe_values, P_swab_values, c=swab_colors[i],
label=f'Swab Pressure at {L} ft depth')
    """

    """
    # Case 5 - changing hole size - D_hole
    D_hole_values = np.array([7.875, 8.375, 8.875, 9.375, 9.875]) *
0.08333332958
    surge_colors = ['c', 'm', 'orange', 'brown', 'olive']
    swab_colors = ['purple', 'lightseagreen', 'gold', 'steelblue', 'pink']
    for i, D_hole in enumerate(D_hole_values):
        results = [pressure_surge_and_swab(V_pipe=V_pipe, D_hole=D_hole)
for V_pipe in V_pipe_values]
        P_surge_values = [result[0] for result in results]
        P_swab_values = [result[1] for result in results]
        axes.plot(V_pipe_values, P_surge_values, c=surge_colors[i],
label=f'Surge Pressure at {D_hole/0.08333332958:.3f} inches hole size')
```

```
        axes.plot(V_pipe_values, P_swab_values, c=swab_colors[i],
label=f'Swab Pressure at {D_hole/0.08333332958:.3f} inches hole size')

    """

    axes.axhline(y=P_frac, c='r', label='Fracture Pressure')

    axes.axhline(y=P_pore, c='g', label='Pore Pressure')

    axes.legend(loc='upper left')

    plt.show()
```

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