POLITECNICO DI TORINO

Master's Degree
Petroleum Engineering

Master's Degree Thesis

Automatic pack off or high cutting concentration detection by using along string measurements (ASM) along wired pipe

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SUMMARY

Since oil and gas companies realized that drilling more wells, which are frequently characterized by narrow pressure margins, is the next stage in the exploration and production of oil and gas, there has been an increase in interest in the evolution of technology and autonomous systems in drilling operations over the past ten years. Drilling operations must be more precise and sensitive due to the challenges of drilling in tight margin pressure wells, such as depleted reservoirs, deep water, extended-reach wells (ERD), and High Pressure High Temperature (HPHT) wells. These wells are more prone to drilling accidents such pack-off, lost circulation, and formation influx, which increases non-productive time (NPT) and expenses.

To minimize the NPT, which in turn lowers drilling costs and keeps people out of the dangerous region, drilling methods based on automated equipment during drilling operations, such as wired drill pipe (WDP) and along-string measurements (ASM), had to be introduced. A computerized system that monitors, models, and controls the acquisition data—actual physical measurements relayed from the well downhole—is also designed to optimize drilling operations. When compared to traditional drilling procedures, the Managed Pressure Drilling (MPD) methodology with its various variations and methodologies is viewed as a viable alternative for drilling operations in tight pressure margin wells. It is feasible to quickly respond to any unindented influx and to account for pressure variations during circulation and connection by using automated back-pressure management in conjunction with a more precise flow meter, such as the Coriolis flow meter. Rheology and the characteristics of the drilling fluid are crucial during drilling operations. In order to maintain equivalent circulating density (ECD) between the formation pore pressure gradient and fracture pressure gradient and hence prevent drilling issues such formation influx, lost circulation, and stopped pipe, the right mud density, viscosity, and rheology must be chosen.

In this thesis,by real values given from reservoir we used Python programming language to determine pressure differences at given depths and according to this differences found issues which occur in our well

ACKNOWLEDGEMENT

First of all, I would like to thank my family for encouraging me to complete my studies in Italy, especially my mother, who motivated me to study for a master’s degree in Politecnico Di Torino

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Student:

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LIST OF EQUATIONS

$$\theta 600 = 2 * PV + YP * \theta 300 = PV + YP$$

$$PV = \theta 600 - \theta 300$$

$$YP = 2\theta 300 - \theta 600$$

$$n = 3.32 \log(\theta 600/\theta 300)$$

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

$$Vc = \left[\frac{5.82 * (10)^4 * K}{\rho}\right]^{1/(2-n)} * \left[\frac{1,6 * (3n+1)}{ID * 4n}\right]^{n(2-n)}, ft/min$$

$$\bar{V} = \frac{24,5Q}{ID^2}, \frac{ft}{min}$$

If $\bar{V}$> Vc flow is turbulent,

$$P = \frac{8,91 * (10)^{-5} * \rho^{0.8} * Q^{1.8} * (PV)^2 * L}{ID^{4.8}}, psi$$

If $\bar{V}$<Vc flow is laminar ,so :

$$P = \left[\frac{1.6 * \bar{V} * (3n+1)}{ID * 4n}\right] \frac{K * L}{300 * ID}, psi$$

$$P1 = 4,2 * 10^{-5} * \rho^{0.8} * Q^{1.8} * (PV)^{0.2}$$

$$Pa = \left[\frac{2,4 * \bar{V} * (2n+1)}{(ID_c - OD_{dp}) * 3n}\right]^n \frac{K * L}{300 * (ID_c - OD_{dp})}, psi$$

$$Pb = \left[\frac{2,4*\bar{V}*(2n+1)}{(D-OD_{dp})*3n}\right]^n \frac{K*L}{300*(D-OD_{dp})}, psi$$

P5=Pa+Pb

Pbit=P1+P2+P3+P4+P5

NOMENCLATURES

Symbol	Definition
MPD	Managed Pressure Drilling
HMI	Human Machine Interface
ROP	Rate Of Penetration
RSS	Rotary-Steerable System
CLDA	Closed-Loop Downhole Automation
PAS	Process Automation System
ASM	Along String Measurement
WDP	Wired Drill Pipe
IOR	Increased Oil Recovery
BHA	Bottom Hole Assembly
HPHT	High Pressure High Temperature
ECD	Equivalent Circulating Densities
TVD	True Vertical Depth
MD	Measured Depth
WOB	Weight On Bit
YP	Yield Point
PV	Plastic Viscosity

IADC	International Association of Drilling Contractors
WDP	Wired Drill Pipe
UBD	Under Balanced Drilling
EMS	Environmental Management System
NOV	National Oilwell Varco
MSE	Mechanical Specific Energy
WCB	Wet Core Bit
PID	Proportional Integral Derivative
PLC	Programmable Logic Controller
NPT	Non Productive Time
CSV	Comma Separated Values
MWD	Measurement While Drilling
LWD	Logging While Drilling
PWD	Pressure While Drilling
RPM	Revolutions Per Minute

CHAPTER 1

INTRODUCTION

Objective

Formations detection, particularly while passing through high and low pressure formations, is a persistent problem in the drilling process for oil wells. However by applying along string measurements we detect high cutting concentrations and pack off . This thesis aims to create model which can help us to determine this issue in the well by adding some data from our reservoir.

Scope of work

In this thesis, work procedures to find the pressure difference at given points (depths) in well based on simulations in the Python program. The scope of work has been as follows:

-Finding critical and average velocity in each section of well;

-determining flow type and according to flow types finding pressure losses ;

-By given flow rate finding pressure losses, equivalent circulation density(which helps to avoid kicks and fluid losses) and also Bottom hole pressure;

-Finding pressure differences at given points and compare them;

-Repeating all the processes for directional drilling;

-Drawing wellbore profile.

Structure of thesis

This master thesis consists of six chapters, in addition to the CSV files converted to pdf, phyton coding and study case description in tables which added to Appendix.

The first chapter contains the general introduction, which includes the objective of the thesis, background, brief of the scope of work.

The second chapter describes the Automation system, for instance, the Automation properties, control system and the process of the Automation system, monitoring modelling and control.

The third chapter is about pack off, detection of pack off and establish against of pack off situations to prevent potential stuck in pipe

The fourth chapter includes describes the Drilling automation wired drill pipe WDP and Along string measurements ASM.

In the fifth chapter there is explanation of model

The Results and Conclusion have been elaborated in the last chapter, which consists of flow diagrams that describe the arguments for different cases and the work-flow diagram.

CHAPTER 2

AUTOMATION

Introduction

” Automation is a process that makes machines do the workthat was once done by people.”

Industrial automation is a term that refers to processes or systems that operate without the need for human input. Evolving from manual operations to automation is a process that aims to make laboratories and workshops more dependent on machines instead of humans, often with the objective to improve security, safety and efficiency. In practice, it can involve robots but often controlled by humans. Automation is a technology that is used to increase production by making machines more efficient than humans. This is possible because machines can work faster and more accurately than humans, which means that they can produce items much faster than a person could [1].

Automation has many meanings, some of which may be more appropriate for your needs than others. Automation is a process or technology that can be used to achieve outcomes with minimal human input. [2].

Applications of automation

Automation has been growing in popularity recently in many areas such as space, home application, hospital, electrical power generation, and distribution. The technology is widely used in various industries, such as chemical and oil industry.

Properties of Automation

The benefits of automation

A relevant question is: Why automation?. The advantages attributed to automation include:

-The performance efficiency. Reducing the duration of the manufacturing cycle can result in increased productivity and production rates.

- By removing non-productive time, manufacturers can make more products in a shorter amount of time.

- Typical performance of automation compared with workmanship by humans leads to a better quality of the product in the manufacturing process. The use of automation in the workplace has led to a decrease in safety hazards, as opposed to the increased hazards that would otherwise occur with human interaction. [3].

Disadvantage of automation

There are some potential downsides to automation, which can include limitations in what can be automated, and the potential for increased workloads for humans.

-The huge amount of capital costs requires a critical venture in hardware that re- quires a long period of seriously utilize to recoup the contributed
- Need of fabricating adaptability, as generation plans are solidified for long periods. This need of adaptability in fabricating may be unsafe in an industry where alter is fast or unusual.
Instrument support and substitution costs tend to rise since all devices must be dis- amassed simultaneously for particular purposes at normal interims, whether these instruments require it or not.[4]

Automation work principles

Elements of automation

The automation elements of Monitoring, Modeling and Control are used to help control the process of an autonomous system. They help monitor what is happening, predict what will happen next, and regulate the mechanism and behavior of the system

Monitoring stage

System monitoring requires careful consideration of a variety of data. Data analysis is the process of using the computer to discover beneficial information by filtering, transforming and modelling.- Data acquisition refers to the process of measuring real-world physical parameters and converting the measured signals into digital numeric values to be manipulated by a computer.

Those components:

- An electronic sensor or transmitter is used to measure real-world physical parameters and convert those physical measurements into electrical signals
- Signal conditioning circuitry, changes over electrical sensor signals to urge sifted and increased signals into a shape that A/D converters can digitize.
- Analog-to-digital converters (A/D converters) can be used to convert electrical sensor signals into digital values, which can be manipulated by computer.
- A Programmable Logic Controller (PLC) is a small computer that is specially designed to handle incoming events in real-time. PLC has input lines connected to

sensors to detect events and output lines connected to actuators to respond to them. (Figure 2.1)

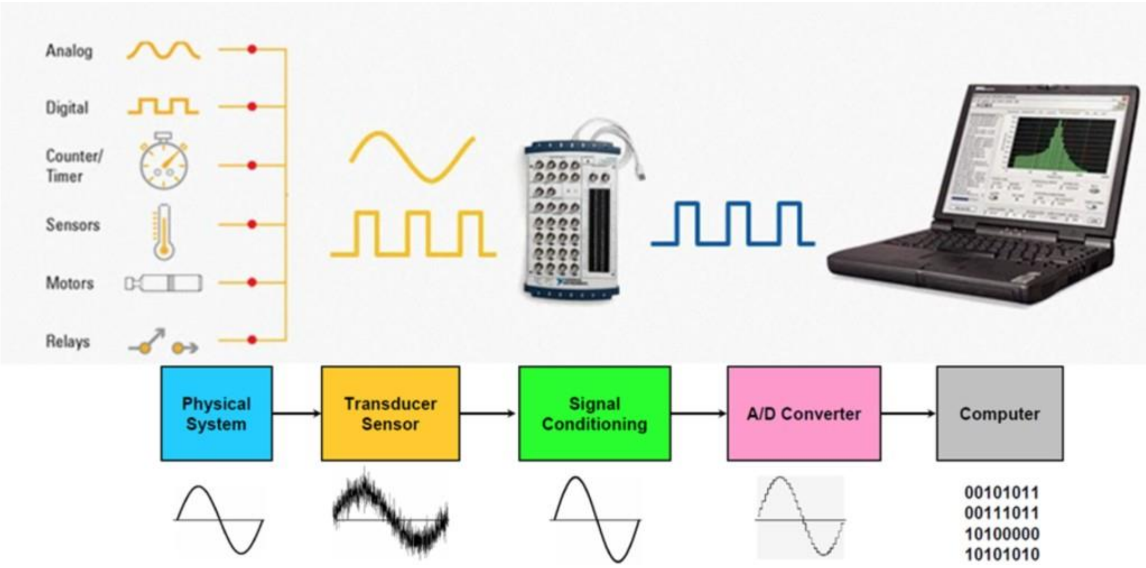


Figure 2.1System of digitalized data acquisition

https://medium.com/daqifi-data-acquisition/types-of-data-acquisition-systems-6ce3d997a2ce

Figure (2.1) This illustration shows the process of converting physical signals into digital signals through the acquisition system.

- Quality control of measured data: Raw data should be subjected to filters and noise reduction procedures to obtain high-quality data.

- Data visualstation: It can be accessed using a human-machine interface, as shown in the figure. (HMI). HMI (or "human machine interface") is a computer software application used to display the status of a process in a graphical form. This allows operators to understand the current state of the process.

The administrators utilize the checked graphical data to acknowledge and execute the control informational, the drillers chair utilized for information visualization. (Figure 2.2)

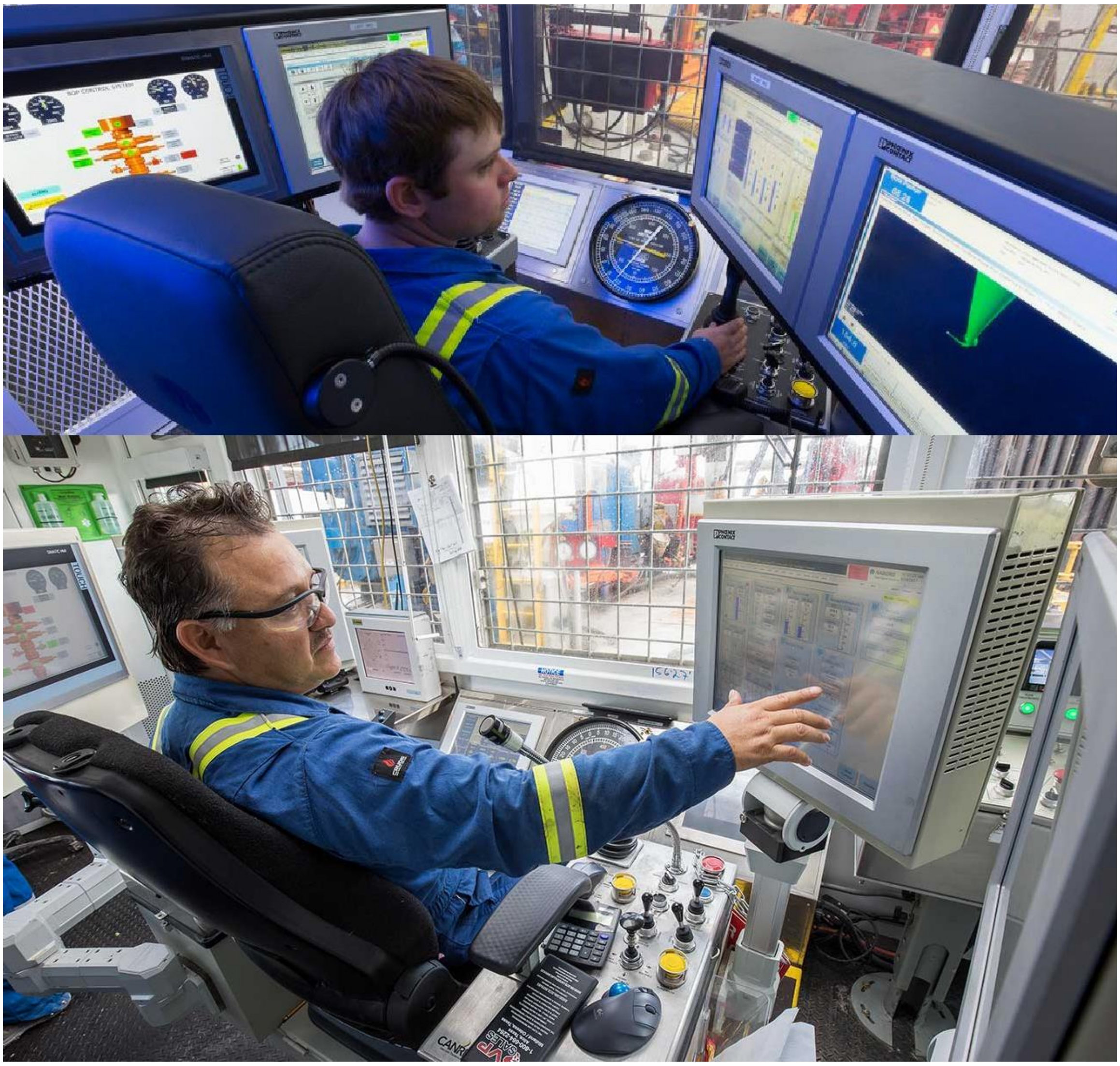


Figure 2.2Driller's chair

[http://www.klondike.no/item/3817/ , http://www.klondike.no/item/3822/]

Figure (2.2) figure appears the driller's chair, which permits the driller to get all data and screen what is happening within the framework in graphical shapes..

Modelling stage

The another step after monitoring what is happening within the framework is creating an fitting demonstrate or a forecast that tells us what will happen within the time.
the issue spoken to to attain an fitting forecast of framework conduct.
Well improved model will be produced with the ideal parameters. For occurrence, the penetrating speed, called rate of entrance (ROP) in penetrating framework can be anticipated more precisely based on genuine penetrating information,

so vital choices basedon information investigation and elucidation strategies are utilized t o construct ROP forecast models.
The suitable model can be produced in drilling framework such as temperature model, Managed Pressure Penetrating (MPD) show, torque and drag model.

Controlling

This step involves the system's behavior being regulated by the control system using control loops. Based on characterizing the objective and required set focuses and accomplishing an fitting created model, the controller whose an fundamental part within the control framework can be outlined.
The Input, Feedforward, and Proportional Indispensably Subsidiary (PID) controller based on control circles alter the digressed yield since of diverse unsettling influences within the processing system to get the required comes about.

CHAPTER 3

PACK OFF

Introduction

Detection of Pack off

Pack-offs can partially or completely block the flow of oil and gas, which can cause delays. Early detection and localization of a pack-off is important so that necessary actions can be taken to avoid downtime. This incident will affect the physical friction between the well and the surrounding environment. A model-based adaptive observer is used to estimate these friction parameters and flow rates.

Oil and gas drilling is fundamentally based on crushing formations with a rotating drillstring and circulating the mass through an annulus around the drillstring, as depicted in Figure. 3. 1. The well can begin to pack off, reducing circulation capabilities, if the formed cuttings are not properly transported out of the well or if parts of the wellbore collapse due to an unstable formation. The drillstring may become stuck if nothing is done, leading to costly delays. As a result, early detection of a pack-off is essential for maintaining proper hole cleaning and avoiding costly wasted time.[5]

Instrumentation has improved as a result of advancements in drilling techniques and technology, such as managed pressure drilling (MPD). According to Godhavn (2010), one such advancement is wired pipe that features pressure (and temperature) measurements along the drillstring and provides real-time data on the wellbore. Long and Veeningen have suggested using this technology for localization and detection of pack-offs. However, it is unclear how these measurements should be applied in an automated diagnosis system. In Aldred and colleagues 1998) as well as Cayeux et al. 2012), an estimated total well friction can be used to detect a pack-off. In Skalle and colleagues 2013), a knowledge-modeling approach is used to diagnose pack-offs and other incidents.[6][7]

The issue of noise exists in all measurement technologies. The goal of this work is to use simple models to quickly locate the incident's location, estimate its size, and detect minor forming pack-offs at an early stage. This is achieved by employing a multivariate statistical change detection framework on estimated friction characteristics and flow rates, enabling quick diagnosis even in the presence of minute estimates changes.

In Willersrud et alearlier .'s paper on fault diagnosis of downhole incidents in drilling, such as gas influx from the reservoir, lost circulation of drilling fluid to the reservoir, drillstring washout (leakage from drillstring to annulus), and plugging of the drill bit nozzles, the topic is continued (2015a,b). Methods are developed there and evaluated using data from a medium-sized test rig. This work uses the commercial high-fidelity multi-phase simulator OLGA to investigate how pack-offs, which were not included in the test rig data, can be diagnosed in simulated data from a full-scale vertical wellbore (Bendiksen et al., 1991).

The following is how the paper is set up: The model and observer, which are used to calculate frictional parameters and flow rates, are presented in Section 2. Sec. 3 presents multivariate statistical prediction and change direction for fault identification. Sec. 4 presents simulations of three possible pack-offs, and Sec. 5 performs fault diagnosis on the simulated data. A conclusion is provided to wrap up the article.[8]

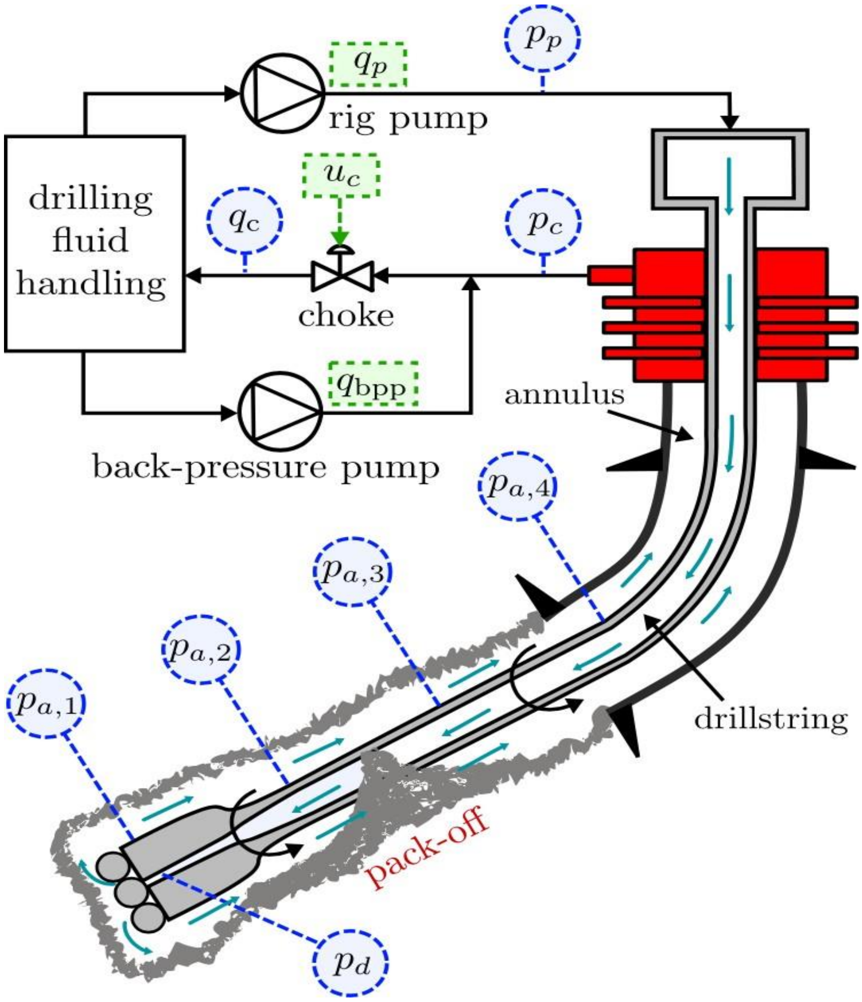


Figure 3.1Generating pack-off during the drilling operstion

Blue for measurements and green for actuators.

Establish against Pack Off Situations to Prevent Potential Stuck Pipe Issues

Flow is impeded or stopped by a pack off, which is a clump of debris, typically cuttings, that has gathered around the drillpipe or BHA. Pack-offs frequently generate stopped pipes and pose a serious risk of fracture in the formation. They often happen where the annular clearing is dropped below normal throughout the string, frequently over the BHA.

Real-time pack-off detection is achievable with a typical PWD, but it takes a very skilled engineer and some luck to catch the early, fleeting interval of pack off spikes. The limited quantity of data that can be pumped up at one time is the main cause of this challenge. Real-time sample rates for PWD data are frequently longer than 1 every 40 seconds as a result of competition for bandwidth with other detectors including formational and directional data. The real time data frequently obscures the transient events.

A standard PWD is sufficient for trend analysis, but it is insufficient for transient and unexpected events like pack-offs. On a traditional PWD tool, recorded data has a high data density, however it is not accessible until the end of the mission. It is difficult to spot a problem in real time until it is serious enough to raise the background ECD level. By that time, either the pack off event has already happened and the pipe is jammed, or the formation has been broken by a pressure surge. [9]However, the smaller short-lived pack-offs can be detected using the high data rates through the composite tubing in real time. Early detection enables the driller to foresee the issue and take corrective action before it worsens.

A full pack-off is frequently preceded under normal drilling circumstances by a number of smaller pack-offs. In order to prevent a full pack-off, corrective action should be made because these little occurrences point to a bigger problem. One of the initial steps is to make an effort to boost the mud's annular velocity. The first step should be to cease drilling if the lesser events happen while it is in drilling mode. This operation halts the addition of fresh cuttings to the mud system, allowing for efficient hole cleaning prior to a further loading of cuttings into the annulus. Stopping drilling has little impact when drilling is sluggish. However, this movement can be important when drilling quickly, when pack offs are most prone to happen.

The PWD tool has many uses, but one of its main ones is for spotting pack-offs or the precursors of one. The tiny events can be observed as they happen due to the high sample rate (2 samples per second), giving the driller time to respond before a full pack-off takes place. Due to the proliferation of cutting beds, packing off is a considerable risk while tripping in a high-angle hole. The ability to continuously flow when tripping is one of the benefits of drilling with coil tubing. With this choice, the annular velocity can be raised by jumping in while circulating. The accompanying two examples included the usage of this technique. (**Figure 3.2 and Figure 3.3**). [10],[11],[12]

In Figure 3.2, the driller decreased the flow and tripping rates before penetrating the casing's milled window during a trip out. When a pack-off happened, the ECD spiked as the tools passed through the window. The driller started tripping back into the hole after instantly switching directions. This prevented formation damage by relieving the pack off. Moreover, the pipe's downward movement generated a brief rise in annular velocity, which assisted in solving the issue.

Figure 3.3 depicts a different pack-off scenario. In this instance, the travel out was halted when the pack-off took place and the pumps were turned off. The driller turned around and reentered the hole. The pack-off was only partially cleaned as a result of this activity, and the driller kept working the pipe. After this initial success, the flow was raised to 90 gal/min and the bend in the three dimensional tool was set to 1°. The journey out was resumed shortly after this action removed the pack off.

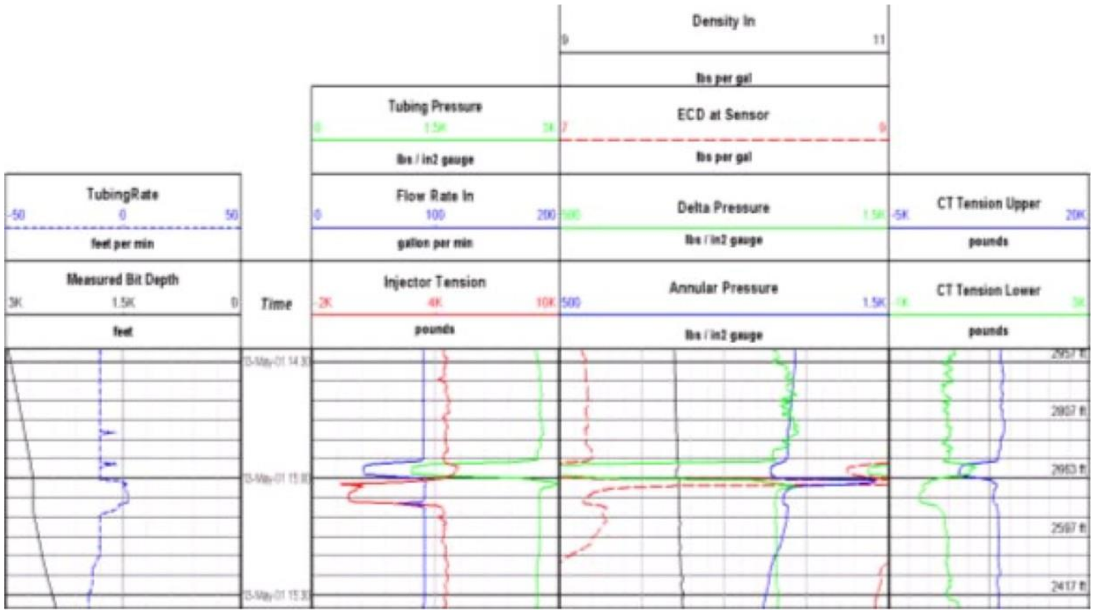


Table 3 1 ECD spike and turn around to clear the pack off.

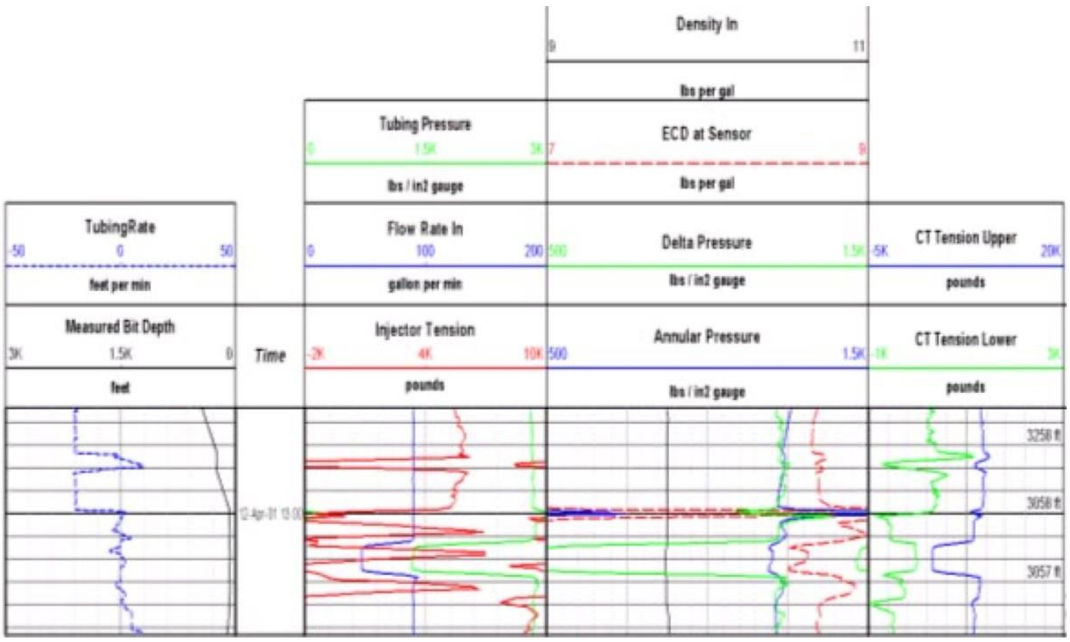


Table 3 2 ECD spike and 3D tool orientation for pack off clearance.

CHAPTER 4

DRILLING AUTOMATION TOOLS

Introduction

Automation of drilling

There has been a paradigm shift in industry history since the discovery of hydrocarbon energy sources, which led to a paradigm shift in industry history, as well as the drilling of the first drilling well in 1859[13], which has resulted in many problems and hazards in the oil industry that have caused human and economic losses.In order to ensure that most drilling operations were automated until automation was introduced into most drilling operations, one of the reasons was to encourage the oil companies to develop drilling and production methods. Obtaining the desired results requires a combination of drilling fluid systems, ROP optimization, well integrity, cementing operations, downhole automation, and the rig floor.

As drilling operations have evolved over the last decade, there has been a growing interest in the evolution of technology and autonomous systems, focusing on fully automated systems, or what is called a robotized system to replace manual labor in drilling operations.

Separating drilling automation from rig floor automation, which deals with mechanized surface operations, where machinery takes the place of human physical labor in the mechanization process, is made easier by the convergence of two important trends: automation and mechanization. The human still controls the machines in some situations, such as on modern drilling rigs with highly automated pipe-handling systems, but in automation systems, the level of human intervention has been diminished to the point where the computer now controls the machinery throughout processing stages.

The downhole behavior and its physical measures are estimated during drilling automation based on supervisory control, computer, and human monitoring. This estimation occurs in nearly real-time. Through a linked connection with parts of the bottom hole assembly, measurements can be sent to the surface (BHA). The information is utilized for analysis, forecasting, and the creation of new models. [14][15][16]

Compared to more manually controlled and regulated operations, drilling automation has been found to improve drilling operation performance. Automation in drilling operations has many advantages, including [17][18][14][19]:

- Lowering human participation lowers potential risks and dangers for workers
- High precision and quality: For jobs that humans undertake, an automation system can reach high rates of accuracy.
- Flexibility: Depending on the setup of the equipment, automation can be tailored to accomplish the tasks.
- Consistency: Compared to the degrees of consistency attained by humans, the same task can be completed repeatedly with the same consistency.

The improvement of drilling efficiency and the decrease in coasts serve as examples of the effects of an automated drilling system. An good illustration of the effectiveness of automation in drilling operations is the automated rig activity at Halliburton. One benefit of automated drilling systems is the reduction of non-productive time (NPT), where NPT approaches use pipe stuck and Rate Of Penetration (ROP) as indications of NPT. The 2013 IADC Critical Issues Asia Pacific Conference, held in Bangkok on November 20–21, served as an example of how automated rig tasks can contribute to time and cost savings.The automated system used by Halliburton is built using a common algorithm for activity analysis. This analysis can be broken down into three basic activities: tripping in, tripping out, which can be defined by the riser, casing liner, and open-hole environment, and drilling. This can be applied to a variety of rig operations, including drill speed, bit depth, flow rates, rotational speed, and hook-load or in-slips measurements. [20]

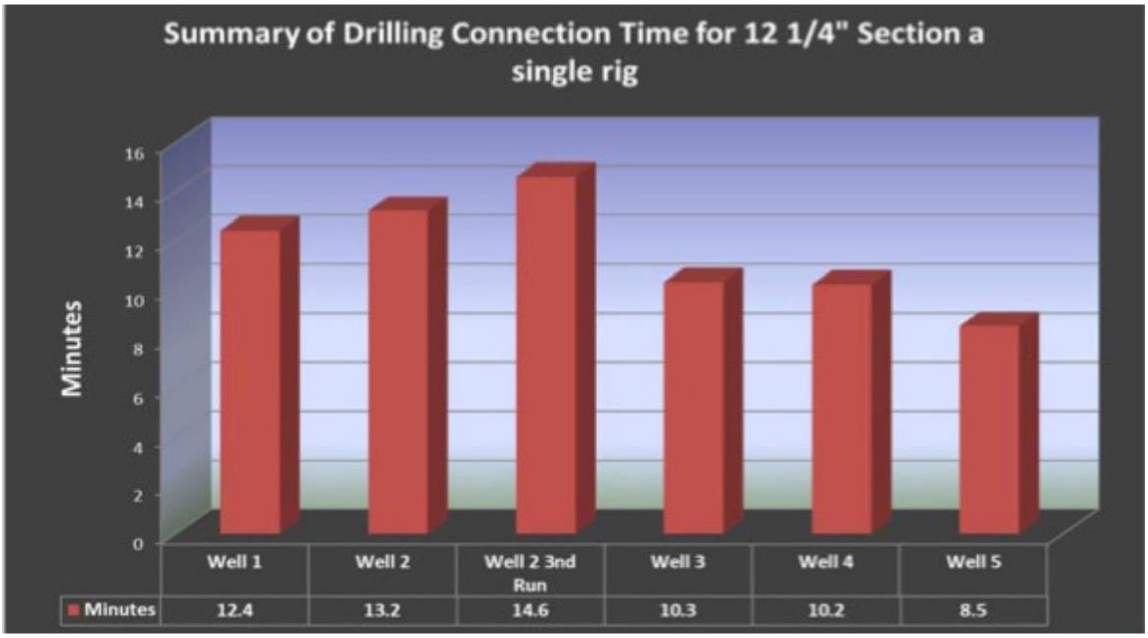


Figure 4.1Halliburton's automated rig

Figure [4.1] shows the connection times which is reduced to 8.5 min after several wells/ the reduction of 172 min for the 12 1/4 in section/. Using Halliburton's automated rig activity measurement and reporting identification system, an operator

was able to cut connection times in the Asia Pacific region by a total of 172 minutes in a 12-inch well section . The oil and gas business as a whole is currently demonstrating the trend towards automation. It is employed in several offshore applications, such as Managed Pressure Drilling (MPD), Expandable Tubular Technology, High Speed Well Communication, Rotary-Steerable System (RSS), and Steerable Drilling Liner, to optimize the drilling process. Tracking Bits in Real Time The bottom hole assembly, which includes MWD, LWD, and PWD, as well as real-time interpretation techniques such well placement, reservoir mapping, and geo-steering, drilling fluid rheology and characteristics, drilling fluid pumps systems, and cementing operations, are semi-autonomous with seismic data.

Review of the drilling automation system

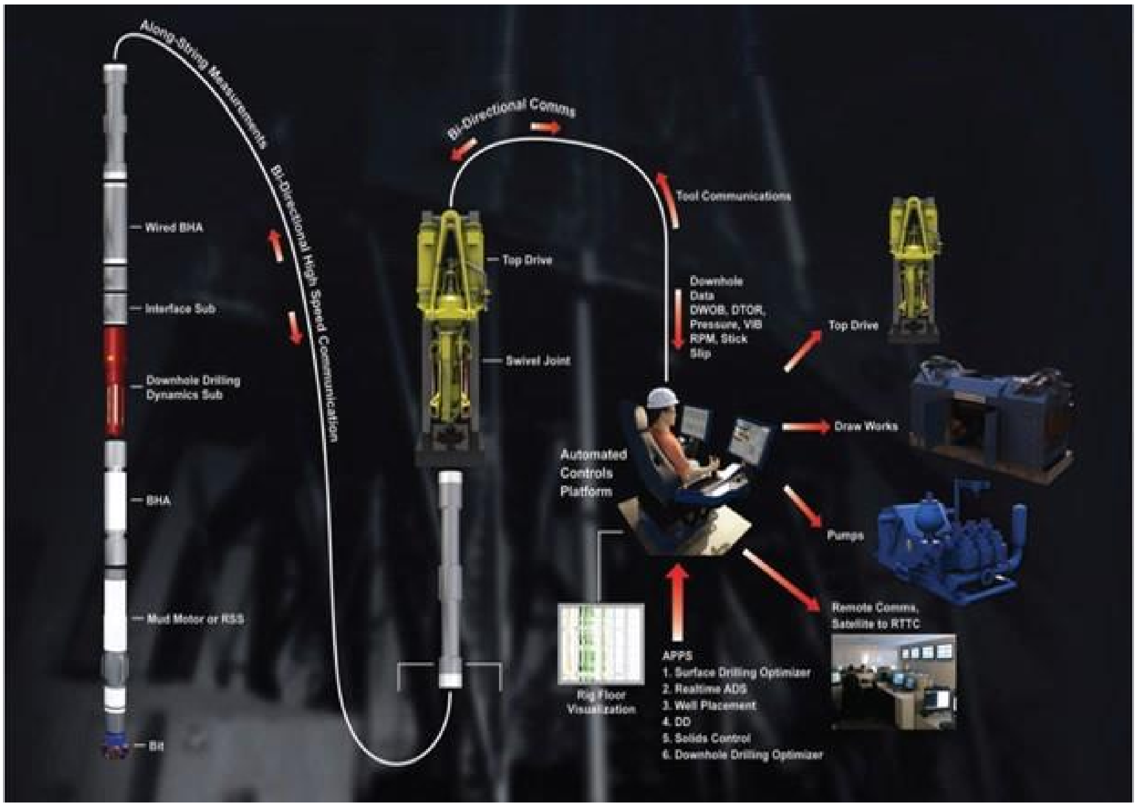


Figure 4.2: Automated System for Drilling Wells https://www.aogr.com/magazine/cover-story/automation-of-downhole-surface- components-optimizes-drilling-process

The figure 4.2 provides a system review that is automated and that can be applied to any rig type without requiring the crew to undergo additional training.

When combined, Closed-Loop Downhole Automation (CLDA) and Process Automation System (PAS) can be used to create an integrated drilling automation system. The bottom rate of penetration (ROP), bit run lengths, and the number of trips resulting from downhole tool failure can all be improved thanks to CLDA. In addition, PAS enables switching from machine controller to process controller, enables the rig to run without conservative safety margins, and aids in fully autonomous processing on the bottom.

The example below illustrates how CLDA and PAS affected the drilling process when drilling the first two 121\4-in. hole sections: [21]

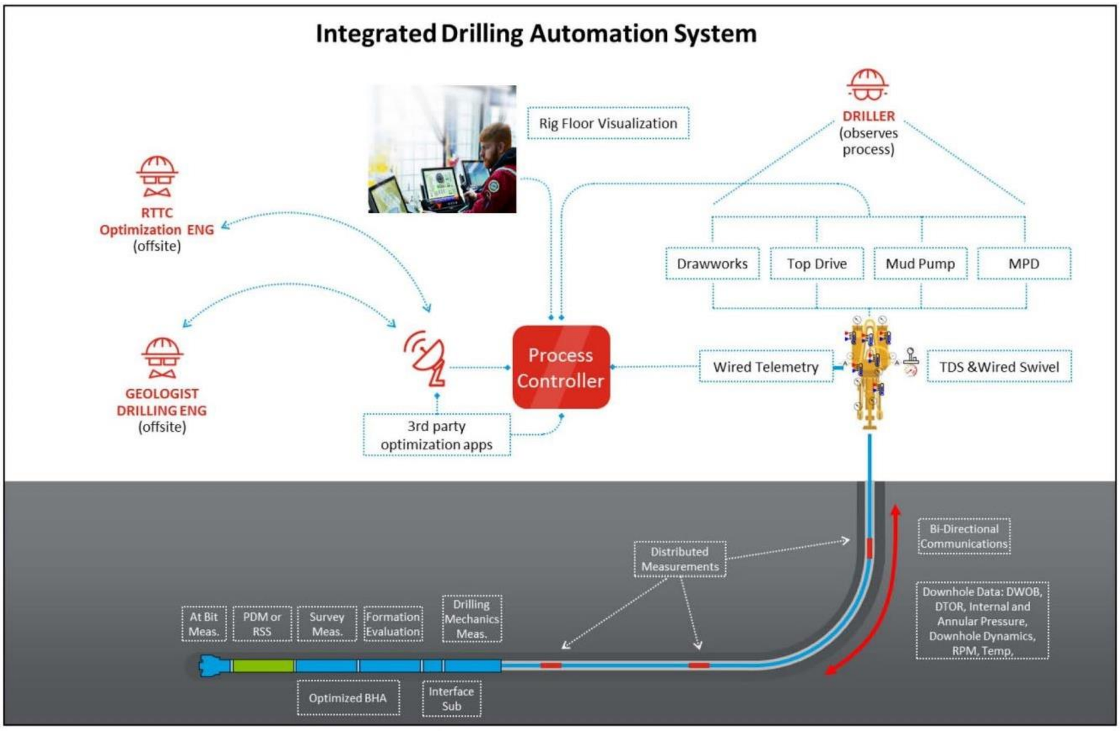


Figure 4.3: Integrated Drilling Automation System

Figure [4.3shows the two systems that make up the Integrated Drilling Automation System (PAS and CLDA).

The PAS System is the piece of software that enables autonomous drilling for the drillers. The system has various control points that affect how the bit engages the formation, such as adjusting the bit RPM prior to engagement, bit RPM following engagement, flow rate prior to and following bit interactions, cetera.

This system requires very little additional hardware and plugs right into the controller cabinet or (PLC) house. Designing a well that enables the driller to know the types of drilled formations, depth, hole size, and final casing location is important in order to help the driller predict and describe the behavior of the drilling operation.[21]

System for Closed-Loop Downhole Automation (CLDA): The CLDA service aimed to cut down on drilling time. The section was drilled in 5.9 days thanks to the CLDA service, resulting in a net savings of 32 percent and 2.8 days overall.

Instruments for automating drilling

Drilling automation is thought to be the future of the oil and gas industry, which has experienced significant automation in recent years. As an alternative to addressing issues with traditional well operating, the advancement of petroleum technology requires a greater emphasis on innovation and downhole measurements. Drilling automation instruments that offer efficient downhole connection and data transfer are crucial components of the drilling automation system.

Wired Drill Pipe (WDP)

There has been a rise in demand to address the difficulties that oil and gas firms have encountered when drilling wells, particularly in High Pressure High Temperature (HPHT) wells, deep water wells, and other wells with a small geopressure margin. Previously, wired drill pipe could be used to obtain data from downhole measurements during drilling. This provided a high-quality transmission network for real-time measurements from the wellbore to the surface, thus optimizing drilling procedures. In order to solve drilling issues, it was necessary to communicate high-quality, high-speed data from a well downhole to the surface, which resulted in the shift of data transmission technologies toward Wired Drill Pipe technology and away from standard mud pulse telemetry technology.

Through WDP and other wired drill string components, wired pipe technology, a high-speed data network, enables real-time communication between downhole tools and the surface systems. The network of downhole pipes consists of:

Data SwivelsTM,
DatalinksTM,
Wired drill pipe and
Special components such as reamers, stabilizers, jars and IBOPs.

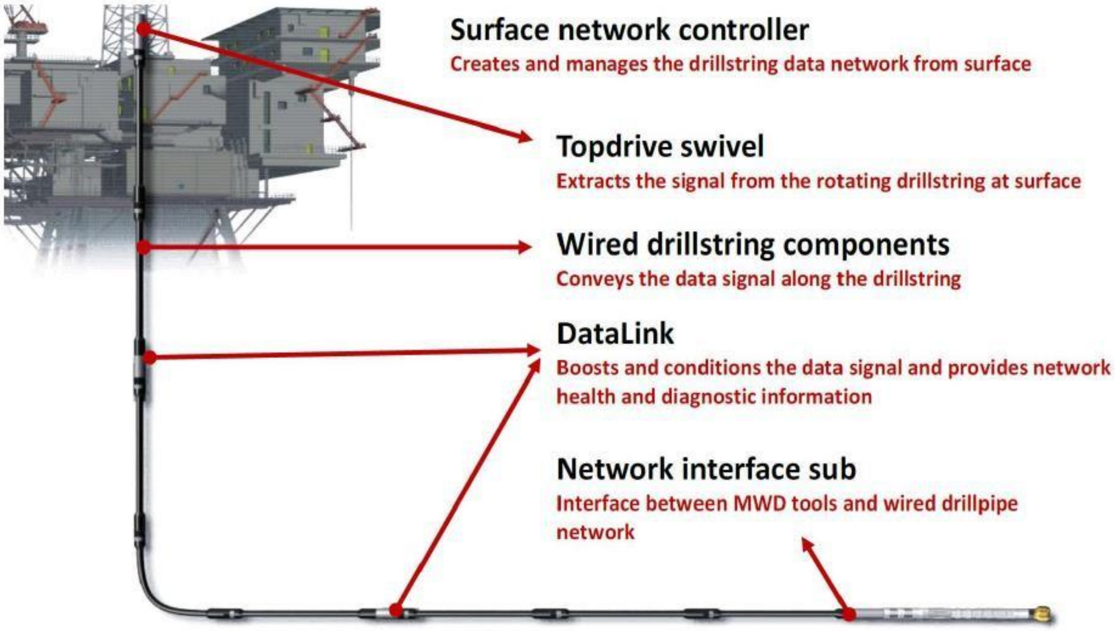


Figure 4.4. Outline of WDP netw ork (NOVMaterial)

Surface cabling and a surface network controller (NetCon)

To securely send tool commands and data in real time to numerous users from a local user, a network controller is needed. Surface cabling, a type of network cable that has been made specifically, is set up to comprehend daily rig operations. This includes all necessary wires and installation-related junction boxes. As shown in Figure 4.4, surface cabling is deployed throughout the rig structure to facilitate data transfer from data swivels to the surface network.

Data Swivels

The downhole system and the surface communicate via a specific connection called a swivel to transmit data. Subsequent to the top drive, this is attached. The data swivel, which is a two-part tubular component and is depicted below, uses a rotor and a stator to create a path between the network's downhole rotating portion and the surface stationary system. The crucial component of the wired pipe system is the data swivel. The swivel can be put above the IBOP or between the saver sub and IBOP depending on the top drive configuration.

Figure 4.5 depicts the optimizing drilling performance using high-speed telemetry and a closed-loop digital platform based on IntelliServTM wired drill pipe and BlackStreamTM downhole sensors, which enable bi-directional downhole data transmission to quickly obtain downhole measurements. Drillers may access clear and accurate data during virtualisation and analysis thanks to IntelliServ wired drill pipe, which offers data communication speeds of up to 57,600 bits per second. [22]

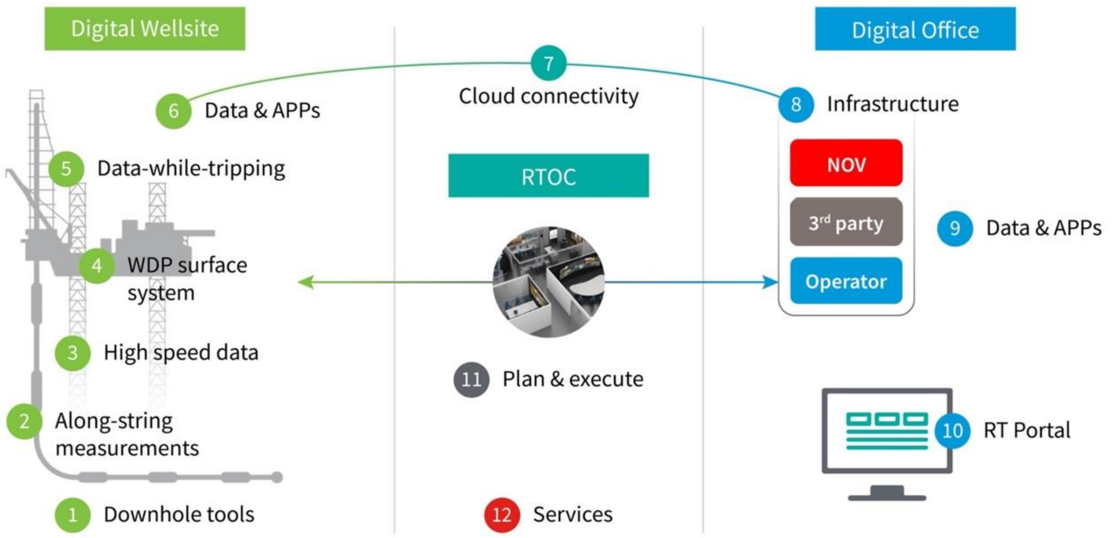


Figure 4.5: Downhole Broadband Solution https://www.nov.com/products/downhole-broadband-solutions

Benefits of implementing WDP telemetry technology [27]:

- The rig saves time by providing the drillers with speed communicated data that provides information on downhole measurements, allowing them to tackle various drilling obstacles.
- The obtained real-time data from WDP was used to constantly enhance the ROP throughout drilling in the well and reservoir section in order to optimize the wellpath and reservoir exposure.
- Geosteering is optimized as a result of the wired drill pipe network's dependability and the formation's high quality evaluation.
- ASMs sensors are used to monitor wellbore conditions including equivalent circulating density (ECD), identification of an early kick in the well, and lost circulation by measuring internal and annular pressure, temperature, and other variables.
- In addition to reducing rig time and guaranteeing that the drilling operation is optimized with rapid data transfer, using WDP telemetry technology also enhances safety and lowers the danger level when drilling.
- Figure [4.6] illustrates how the NOVOS system, which collaborates with wired drill pipe in Alaska's North Slope to achieve 95% uptime with wired drill pipe and improved overall drilling performance on project wells versus offsets, lowers costs, improves ROP, and increases drilling efficiency by Mechanical Specific Energy (MSE). [23]

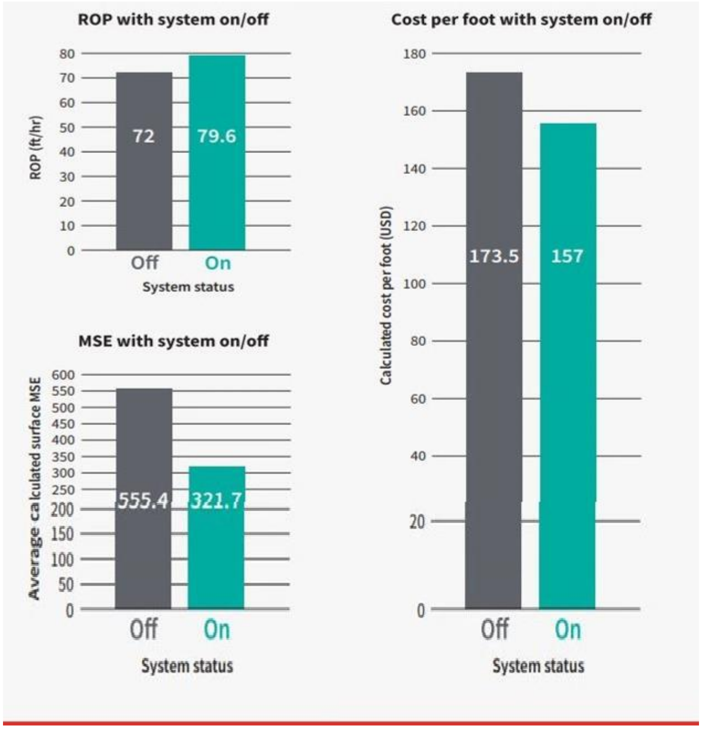


Figure 4.6: NOVOS SYSTEM EFFICIENCY

Along string measurement (ASM)

WDP technology creates new opportunities for down-hole and surface communication using a variety of sensors. The wired drill pipe network technology used by AlongString Measurements (ASM) consists of a number of sensors that can be installed at various points along the drill stringAs a component of the WDP, ASMs offer network connectivity by determining downhole physical characteristics and assisting in the fast transmission of data so that it can be seen on the drill floor in real time, even when the flow is interrupted. The advantages of ASMs include identifying pack-off spots, evaluating downhole incidents, and early detection of a kick employing annular/internal pressure and temperature sensors. Higher - frequency measurements of rotation and vibrations are obtained along the drill strings, which can be used to describe the borehole conditions there and at the bottom hole assembly. ASMs can also assist in seeing real-time hole cleaning and adjusting variables like ROP, RPM, and flow rate.[24]

BlackStream alongstring measurement (ASM) tools from National Oil well Varco (NOV) were made available to the oil and gas sector as WDP components, see [4.7], and have a flexible location along the drill string. By including temperature, annular/internal pressure, three-axis vibration, and rotating velocity sensors, BlackStream ASM tools are utilized to assess the drillstring's dynamic environment. Additionally, the BlackStream ASM tool may gather data on equivalent circulation densities in real-time. It is attached to the IntelliServ networked drill string, which facilitates the acquisition of high-quality downhole data aimed at improving drilling process components like pressure profile and wellbore condition.[25]

Figure [4.7] displays the IntellServ Network's six essential parts, which work together to run the system:

• Data Swivel TM
• NetCon TM and Surface Cabling
• Wired Drillstring and components
• DataLinksTM
• BlackStream ASM and EMS
• BHA Interface Sub

Along the drillstring, various sensor types can be dispersed as follows:

• Pressure sensors
• Temperature sensors
• Strain gauges

• Inclinometers
• Accelerometers
• Bending, vibration, and rotation sensors
• Flow-rate sensors, and many more
• Sensors measure wellbore stability, resistivity, ECD measurements

In Figure [4.9a], a networked drill string with dispersed downhole pressure and temperature measuring sensors that allows analyzing the wellbore condition from the surface to the bottom.[26]

Along String Measurements implements can be used in a variety of drilling techniques and solutions to spread the ASM along the drillstring in the wellbore. For illustration, Using ASMs, find early kick incidents .When drilling operations are dependent solely on surface measurements or when digging a deep-water well and the data flow, several difficulties and well mishaps take place.

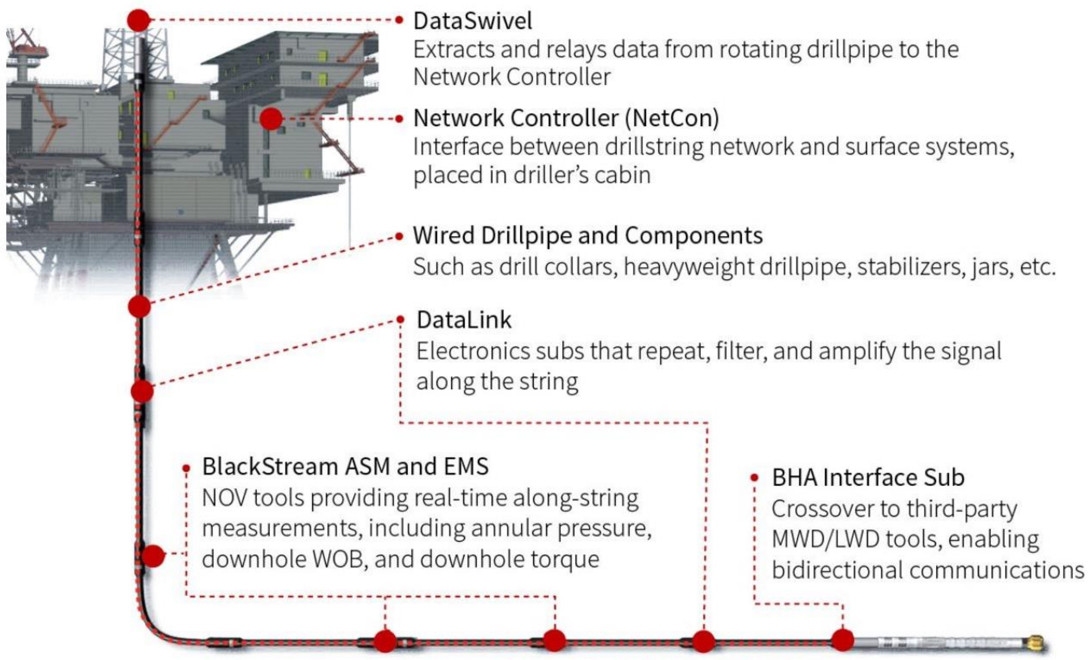


Figure 4.7: overview of the IntelliServ network including the BlackStream ASM
https://www.hartenergy.com/exclusives/highway-downhole-data-delivers- optimized-drilling-176314

One of these instances is the formation influx that causes a kick in the wellbore; to deal with this problem and reduce the possibility of a blowout, early detection of the kick is essential.

To pressurize the annulus and monitor pressure changes along the wellbore, sensors are placed along the drill string and close to the bit. This tool aids in the early detection of the kick so that the Managed Pressure Drilling system can operate and automatically modify the ECD to circulate the kick. Figure [4] .8] The well kick is demonstrated in the example below, along with the flowchart choice to detect the kick. For the purpose of measuring the annular pressure in different time ,four sensors are dispersed along the drill string (0,1,2,3). When the corresponding pressure gradient is reduced due to the formation influx, the first sensor, which is closest to the bit, records the annulus pressure change. The other sensors record the annulus pressure change when the high kick starts to decrease and reaches the sensors that are placed above. Less than 10 seconds are required for the network drill pipe system to start the kick circulating and maintain a healthy safety pressure margin. [26].

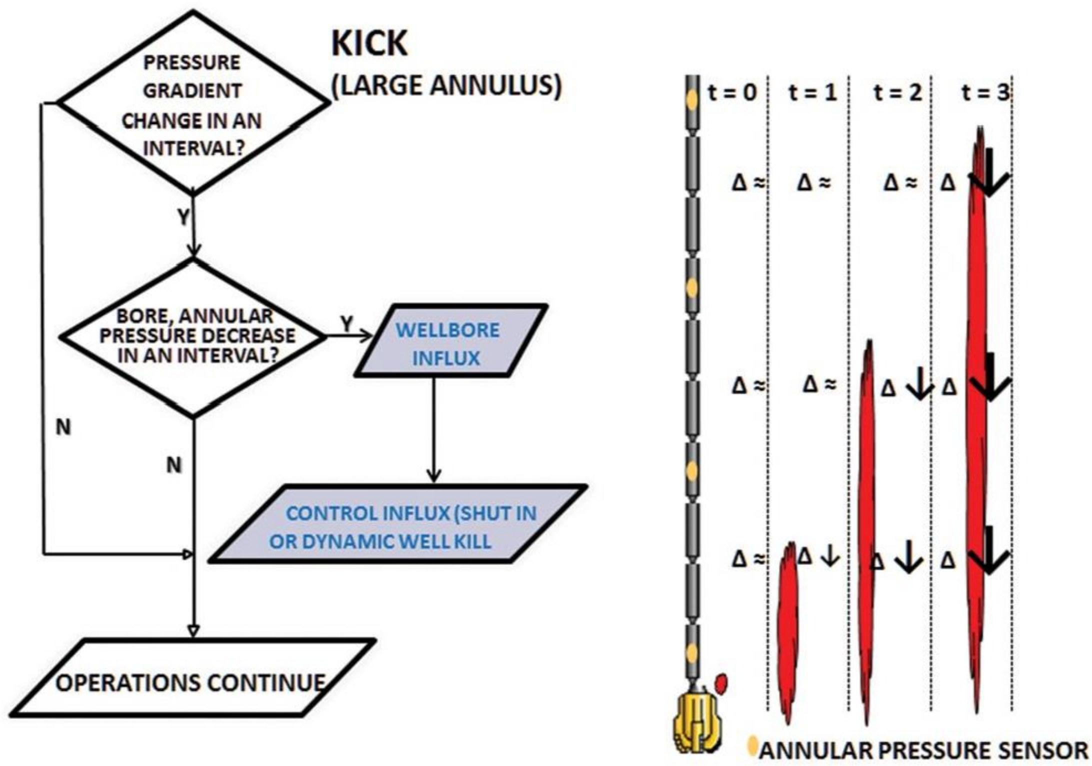


Figure 4.8: ASMs Kick and FlowChart

Six along-string annular pressure sensors are depicted in Figure [4.9b] to help with the investigation of fluid migration in the annulus. The sensors disclose the position of fluids within the annulus utilizing downhole data provided by the wired drill pipe. Additionally, it shows how the influx would result in a decrease in pressure whereas kill mud moving up the annulus would result in an increase in pressure.[26]

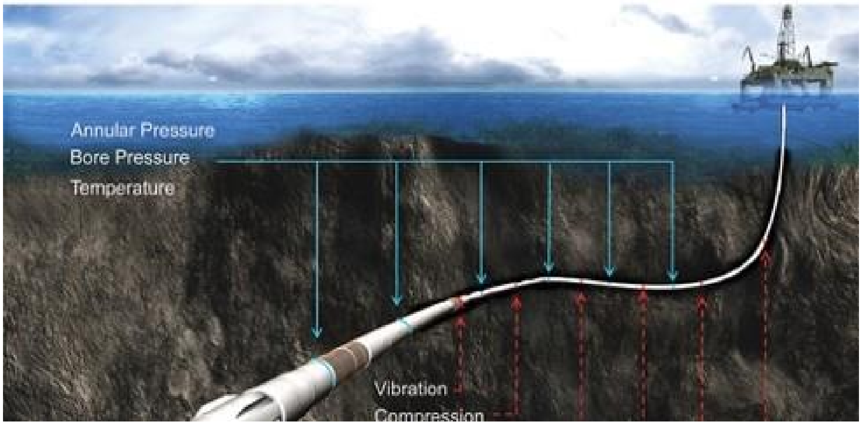


Figure 4.9(a) Pressure and temperature measurements disseminated throughout a networked drill string
[https://www.drillingcontractor.org/wired- pipe-delineates-safer-drilling- margins-2-14010](https://www.drillingcontractor.org/wired-pipe-delineates-safer-drilling-margins-2-14010)

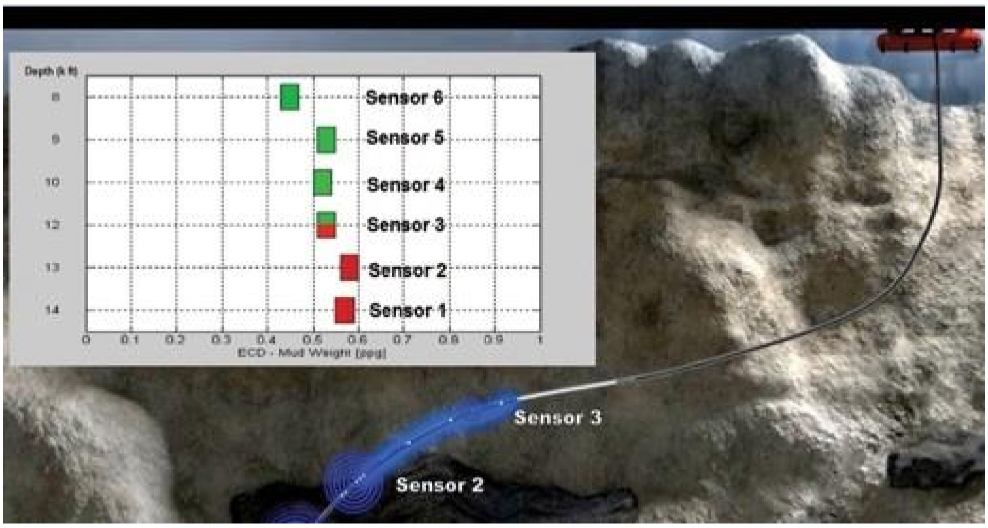


Figure 4.9(b) The dynamic pressure over the mud weight is recorded by six along-string annular pressure sensors.

https://www.drillingcontractor.org/wired- pipe-delineates-safer-drilling- margins-2-14010

CHAPTER 5

EXPLAINATION OF MODEL

Introduction

We create model which can automatically calculate pressure losses in each section of well. Firstly we assume our well is vertical , then we also look for directional wells case.For this we can use Bingham plastic and power-law models, in this paper I used power law model as it is for non-Newtonian fluids . A typical rheological model to quantify the Shear Thinning is the power law model. Shear thinning or pseudoplastic flow, in which the fluid viscosity lowers with increased shear, is the most prevalent type of non-Newtonian behavior. Shear thinning characteristics of a sample; a number nearer to zero denotes a material that is more shear thinning.We have our input d ata given from one reservoir in Norway.

SPP (psi)	MD bit (ft)	TVD bit (ft)	simulated pressure at bit by power law model (psi)	MD Borehole (ft)	TVD Borehole (ft)	simulated pressure at bit by Herschel Bulkley model (psi)
1402.00467	7849.07068	6355.03452	3505.652677	7849.07068	6355.03452	3434.385681
1402.081482	7849.10349	6355.03452	3503.727704	7849.10349	6355.03452	3432.364832
1402.15534	7849.10349	6355.03452	3501.945749	7849.10349	6355.03452	3430.494235
1402.226411	7849.10349	6355.03452	3500.497555	7849.10349	6355.03452	3428.96369
1402.160507	7849.1363	6355.03452	3499.547331	7849.1363	6355.03452	3427.936567
1401.80682	7849.1363	6355.03452	3498.080865	7849.1363	6355.03452	3426.398478
1401.880307	7849.16911	6355.03452	3496.707018	7849.16911	6355.03452	3424.95741
1401.951216	7849.16911	6355.03452	3496.009382	7849.16911	6355.03452	3424.196911
1401.894602	7849.16911	6355.03452	3495.353622	7849.16911	6355.03452	3423.482078
1401.643175	7849.20192	6355.03452	3494.307872	7849.20192	6355.03452	3422.380518
1401.617763	7849.20192	6355.03452	3493.074222	7849.20192	6355.03452	3421.094413
1401.712111	7849.23473	6355.03452	3492.229773	7849.23473	6355.03452	3420.200216
1401.592802	7849.23473	6355.03452	3491.392897	7849.23473	6355.03452	3419.316451
1401.54637	7849.23473	6355.03452	3490.37075	7849.23473	6355.03452	3418.249872
1401.750763	7849.26754	6355.03452	3489.696962	7849.26754	6355.03452	3417.533725
1401.948866	7849.26754	6355.03452	3489.05808	7849.26754	6355.03452	3416.854778
1401.789233	7849.30035	6355.03452	3488.625658	7849.30035	6355.03452	3416.384042
1401.720987	7849.30035	6355.03452	3489.430977	7849.30035	6355.03452	3417.246082
1401.590737	7849.30035	6355.03452	3490.097278	7849.30035	6355.03452	3417.966451
1401.674538	7849.33316	6355.03452	3489.538981	7849.33316	6355.03452	3417.370802
1401.486491	7849.36597	6355.03452	3488.844075	7849.36597	6355.03452	3416.640189
1401.508094	7849.36597	6355.03452	3489.574356	7849.36597	6355.03452	3417.42142
1401.529097	7849.36597	6355.03452	3490.088067	7849.36597	6355.03452	3417.983901
1401.629026	7849.39878	6355.03452	3489.697318	7849.39878	6355.03452	3417.558338
1401.471366	7849.39878	6355.03452	3489.323806	7849.39878	6355.03452	3417.151614
1401.472673	7849.43159	6355.03452	3490.04245	7849.43159	6355.03452	3417.916293
1401.473946	7849.43159	6355.03452	3491.381737	7849.43159	6355.03452	3419.333665
1401.475186	7849.43159	6355.03452	3491.846025	7849.43159	6355.03452	3419.797953

Table 5 1 Simulated PWD data

As input we use :

Length of casing=2550ft	Outside diameter of casing=13.725 in	Inside diameter of casing=12.565 in
Length of drill pipe=6480ft	Outside diameter of drill pipe=5 in	Inside diameter of drill pipe=4.276 in
Length of drill collar=620 ft	Outside diameter of drill collar=8 in	Inside diameter of drill collar =2.87 in

We assume mud density is 8.824 Ib/gal
Plastic velocity =12 cP
Yield point =12 Ib/100ft2

We determine the various pressure drops, nozzle velocity and nozzle sizes

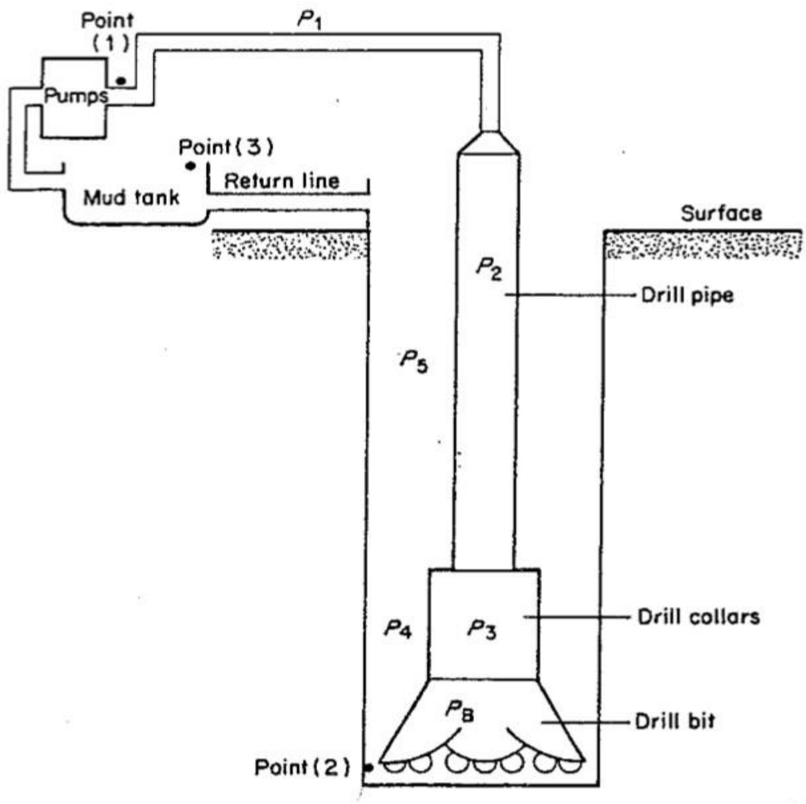


Figure 5.1:Schematic drawing of the circulating system. Points (1) and (3) are assumed to be at the same level

Case 1.

Calculations for uninclined wells

I assumed flow rate inside well is Q=700 gpm.
Firstly, we have to calculate consistency index(k) and also flow index(n)

*k- Measure of consistency of the fluid. The higher, the more viscous. n- Measure of the degree o non-Newtonian behaviour. The greater the distance from unity, the more pronounced are the Non- newtonian proper26es.

The apparent viscosity reported for 300RPM(theta 300) or one half of meter reating at 600 RPM(theta 600)

$\theta 300$=24 RPM

$\theta 600 = 2 * PV + YP * \theta 300 = PV + YP$=36 RPM

$n = 3.32 \log(\theta 600/\theta 300)$=0.584623

$K = \frac{\theta 300}{511^n}$ =0.626334

Now we can calculate pressure losses for each sections.

Surface losses (P1) =4,2*$10^{-5} * \rho^{0.8} * Q^{1.8} * (PV)^{0.2}$= 52.094804334237494

We use same equations also for Pressure losses inside drill pipe (P2), inside drill collar

(P3), around drill collar (P4)

P2= 669.9107
P3= 434.4916
P4= 5.456023
For finding annular losses , first we find annular distance D=IDc-OD=inside diameter of

13 3/8 casing – Outside diameter of drill pipe.Annular losses divided two parts

$$Pa = \left[\frac{2,4 * \bar{V} * (2n+1)}{(ID_c - OD_{dp}) * 3n}\right]^n \frac{K * L}{300 * (ID_c - OD_{dp})}, psi$$

For open hole section:

Annular distance=Hole diameter- Outside diameter of drill pipe.

We calculate Pb

$$Pb = \left[\frac{2{,}4 * \bar{V} * (2n+1)}{(D - OD_{dp}) * 3n}\right]^n \frac{K * L}{300 * (D - OD_{dp})}, psi$$

P5=Pa+Pb

P5= 25.16762
Then we calculate pressure drop across bit:

Pbit=P1+P2+P3+P4+P5= 1187.121

ECD= 8.916669
BHP= 2924.911549

From our model we see our flow is turbulent for P1,P2,P3 and laminar for P4 and P5

For the next step we determine 3 point which are 50 ft above final depth;650 ft above and 1200 ft above final depth. Our final depth D=7100 ft, so our determined points are TVD_1=7050 ft, TVD_2=6450ft ; TVD_3=5900ft.

Q (gpm)
474.031687
473.8494372
473.982378
474.1103022
474.2334885
474.3521952
474.4666625
474.5771133
474.6837555
474.7867827
474.8863756
474.9827033
475.0759235
475.1661844
475.2536247

Table 5 2 This data is simulated PWD data and I used 64765 data for each parameter in my model.

For each given flow rate we calculate P5 (I called them as P_TVD_1, P_TVD_2, P_TVD_3 corresponsible)for our determined points . Then we have to determine pressure difference between them (delta_P_TVD_1=P_TVD_1- P_TVD_2 , delta_P_TVD_2=P_TVD_1- P_TVD_3 ,delta_P_TVD_3=P_TVD_2-P_TVD_3)

Q	P_TVD_1	P_TVD_2	P_TVD_3	delta_P_TVD_1	delta_P_TVD_2	delta_P_TVD_3
474.0317	31.12138	28.47275	26.044842	2.648627996	5.076536992	2.427908996
473.8494	31.11438	28.46635	26.0389874	2.64803262	5.075395855	2.427363235
473.9824	31.11949	28.47102	26.0432581	2.648466922	5.076228268	2.427761345
474.1103	31.1244	28.47551	26.0473671	2.648884788	5.077029177	2.428144389
474.2335	31.12912	28.47984	26.0513235	2.649287133	5.077800337	2.428513205
474.3522	31.13368	28.484	26.0551356	2.649674806	5.078543377	2.428868572
474.4667	31.13807	28.48802	26.0588112	2.650048595	5.079259807	2.429211212
474.5771	31.14231	28.4919	26.0623575	2.650409233	5.079951031	2.429541797
474.6838	31.1464	28.49564	26.0657811	2.650757403	5.080618356	2.429860953
474.7868	31.15035	28.49926	26.0690884	2.651093739	5.081263	2.430169261
474.8864	31.15417	28.50275	26.0722852	2.651418836	5.081886102	2.430467266
474.9827	31.15787	28.50613	26.0753769	2.651733246	5.082488722	2.430755476
475.0759	31.16144	28.5094	26.0783686	2.652037489	5.083071854	2.431034365
475.1662	31.1649	28.51257	26.0812652	2.65233205	5.083636429	2.431304379
475.2536	31.16825	28.51564	26.0840709	2.652617384	5.084183319	2.431565935
475.3384	31.1715	28.51861	26.0867902	2.652893917	5.084713341	2.431819424
475.4206	31.17465	28.52149	26.0894268	2.653162051	5.085227264	2.432065213
475.5003	31.17771	28.52429	26.0919846	2.653422163	5.085725812	2.432303649
475.342	31.17164	28.51874	26.0869065	2.652905747	5.084736015	2.431830268
475.1883	31.16575	28.51335	26.0819749	2.652404231	5.083774777	2.431370545
475.2679	31.1688	28.51614	26.08453	2.652664073	5.084272806	2.431608733
475.3453	31.17177	28.51885	26.087013	2.652916577	5.084756772	2.431840196
475.198	31.16612	28.51368	26.0822855	2.65243581	5.083835303	2.431399493
475.0547	31.16063	28.50866	26.0776869	2.651968156	5.082938965	2.430970809
475.1318	31.16358	28.51136	26.0801621	2.652219874	5.083421424	2.431201551
475.2069	31.16646	28.514	26.0825711	2.652464863	5.083890987	2.431426124
475.0691	31.16118	28.50916	26.0781504	2.65201529	5.083029307	2.431014016

Table 5 3Pressure and differences for each points

As we know for security reasons we need our pressures which we got from calculations should not be lower than pore pressure and higher than fracture pressure. We determine window and see if it works well:

TVD	pore_pressure	frac_pressure
5901	8.4	36
5905.01338	8.47733333	35.9668874
5909.02676	8.55466666	35.9337748
5913.04013	8.63199999	35.9006623
5917.05351	8.70933332	35.8675497
5921.06689	8.78666665	35.8344371
5925.08027	8.86399998	35.8013245
5929.09365	8.94133331	35.7682119
5933.10702	9.01866664	35.7350994
5937.1204	9.09599997	35.7019868
5941.13378	9.1733333	35.6688742
5945.14716	9.25066663	35.6357616
5949.16054	9.32799996	35.602649
5953.17391	9.40533329	35.5695365
5957.18729	9.48266662	35.5364239
5961.20067	9.55999995	35.5033113
5965.21405	9.63733328	35.4701987
5969.22742	9.71466661	35.4370861
5973.2408	9.79199994	35.4039736
5977.25418	9.86933327	35.370861
5981.26756	9.9466666	35.3377484
5985.28094	10.0239999	35.3046358
5989.29431	10.1013333	35.2715232
5993.30769	10.1786666	35.2384107
5997.32107	10.2559999	35.2052981
6001.33445	10.3333333	35.1721855
6005.34783	10.4106666	35.1390729
6009.3612	10.4879999	35.1059603
6013.37458	10.5653332	35.0728478
6017.38796	10.6426666	35.0397352

Table 5 4 Pressure window for TVD (one part of it)

Case 2.

Calculations for directional wells

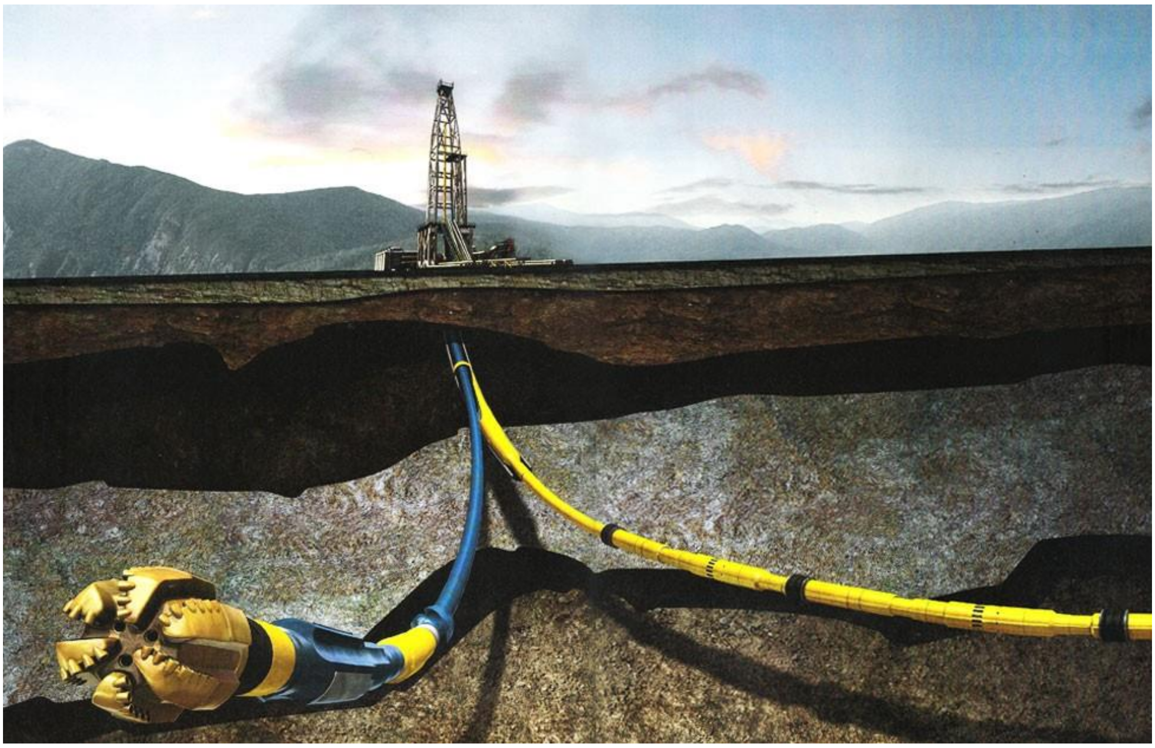


Figure 5.2 Directional drilling

https://globaldrillings.com/2020/06/28/directional-drilling-2/

As we know in real life our wells are mostly directional. Now we have to do same calculations for directional wells . Another name for directional drilling is directional boring.

The calculations for the purposes directional drilling survey are:

- Use deflection tools to steer clear of well routes.
- Identify the precise location of the bottom hole to track reservoir performance.
- Maintain a close eye on the actual path of the well to make sure the goal will be reached.
- Determine each formation's TVD to enable geological mapping.
- Ensure that no other wells close by will be hampered by the well.Analyze the Dog-Leg Severity (DLS), which is the sum of the angular azimuth and inclination in the wellbore, determined over a standard length (100 ft or 30 m).

In first case Measured Depth and True Vertical Depth were same so we just called them TVD, for directional wells our MD and TVD are not equal. Our MD starts from o to 7105 ft.
We assume till one point of well it is vertical (till 6286.28 ft) so our inclination is equal zero, from 6290.29 ft till 6838.11 ft our inclination is 40 ‘ , from 6840.13 ft till bottom (7105 ft) out well is horizontal (inclination is equal 90’)

Firstly, we use Minimum curvature method . It is most accurate directional drilling calculation method. Using the Ratio Factor, the Minimal Curvature Method smoothes two straight-line segments of the Balanced Tangential Method (RF).

$$DL = \cos^{-1}[\cos(I_2 - I_1) - \sin I_1 \sin I_2 (1 - \cos(A_2 - A_1))]$$

$$RF = \frac{360}{DL \bullet \pi} \tan\frac{DL}{2} \quad \text{or} \quad RF = \frac{360}{DL \bullet \pi} \bullet \frac{1 - \cos DL}{\sin DL}$$

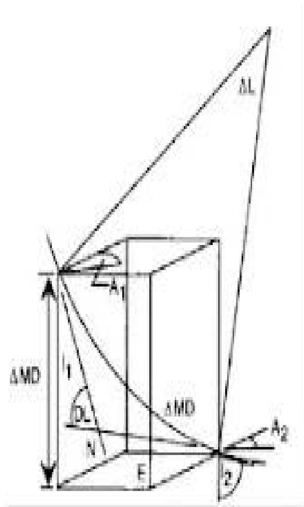


Figure 5.3 Minimum curvature method directional drilling

https://www.drillingmanual.com/directional-drilling-survey-calculations-excel-spreadsheet/

The formulas for the Minimum Curvature Method are listed below;

North south $= \frac{MD}{\&} * [\sin(I_1) * \cos(Az_1) + \sin(I_\&) * \cos(Az_\&)] * RF$

East West $= \frac{MD}{\&} * [\sin(I_1) * \sin + \sin(I_\&) * \sin(Az_\&)] * RF$

$$T\_V\_D=\frac{MD}{2} * [\cos(I_1) + \cos(I_2)] * RF$$

$$DL = cos^{-1}[(\cos(I_2 - I_1) - sin(I_1) * \sin(I_2) * (1 - \cos(A_2 - A_1))]$$

$$RF=\frac{2}{DL} * \tan\left(\frac{DL}{2}\right)$$

MD = Measured Depth between surveys in ft
I1 = Inclination (angle) of upper survey in degrees
I2 = Inclination (angle) of lower in degrees
Az1= Azimuth direction of upper survey
Az2 = Azimuth direction of lower survey
RF = Ratio Factor
DL is the dog leg angle.

alpha	betta	DL	RF	T_V_D	NS	EW	dir	closure	Vertical	dog_leg
0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	500	0	0	0	0	0	0
0	0	0	1	1000	0	0	0	0	0	0
0	0	0	1	1500	0	0	0	0	0	0
0	0	0	1	2000	0	0	0	0	0	0
0	0	0	1	2500	0	0	0	0	0	0
0	0	0	1	3000	0	0	0	0	0	0
0	0	0	1	3500	0	0	0	0	0	0
0.2617994	0	0.2617994	1.005751	3994.308	65.076878	0	360	65.076878	-61.15226	3
0.5235988	0	0.2617994	1.005751	4454.9297	255.87263	0	360	255.87263	-240.4416	3
0.7853982	0	0.2617994	1.005751	4850.4745	559.38484	0	360	559.38484	-525.6498	3
0.7853982	0	0	1	5204.0279	912.93823	0	360	912.93823	-857.8813	1.708E-07
0.7853982	0	0	1	5557.5813	1266.4916	0	360	1266.4916	-1190.113	1.708E-07
0.7853982	0	0	1	5911.1346	1620.045	0	360	1620.045	-1522.344	1.708E-07
0.7853982	0	0	1	6264.688	1973.5984	0	360	1973.5984	-1854.576	1.708E-07
0.7853982	0	0	1	6618.2414	2327.1518	0	360	2327.1518	-2186.807	1.708E-07
0.7853982	0	0	1	6971.7948	2680.7052	0	360	2680.7052	-2519.039	1.708E-07
1.0471976	0	0.2617994	1.005751	7275.307	3076.25	0	360	3076.25	-2890.729	3
1.2217305	0	0.1745329	1.0025462	7486.3481	3528.829	0	360	3528.829	-3316.015	2
1.3089969	0	0.0872665	1.0006351	7636.6533	4005.5361	0	360	4005.5361	-3763.973	1
1.3962634	0	0.0872665	1.0006351	7744.8387	4493.5293	0	360	4493.5293	-4222.536	1
1.4835299	0	0.0872665	1.0006351	7810.0811	4989.0944	0	360	4989.0944	-4688.215	1
1.5707963	0	0.0872665	1.0006351	7831.8839	5488.46	0	360	5488.46	-5157.465	1
1.5707963	0	0	1	7831.8839	5988.46	0	360	5988.46	-5627.312	1.708E-07
1.5707963	0	0	1	7831.8839	6488.46	0	360	6488.46	-6097.158	1.708E-07
1.5707963	0	0	1	7831.8839	6988.46	0	360	6988.46	-6567.004	1.708E-07
1.5707963	0	0	1	7831.8839	7488.46	0	360	7488.46	-7036.851	1.708E-07
1.5707963	0	0	1	7831.8839	7988.46	0	360	7988.46	-7506.697	1.708E-07
1.5707963	0	0	1	7831.8839	8488.46	0	360	8488.46	-7976.543	1.708E-07
1.5707963	0	0	1	7831.8839	8988.46	0	360	8988.46	-8446.39	1.708E-07

Table 5 5Results for directional drilling

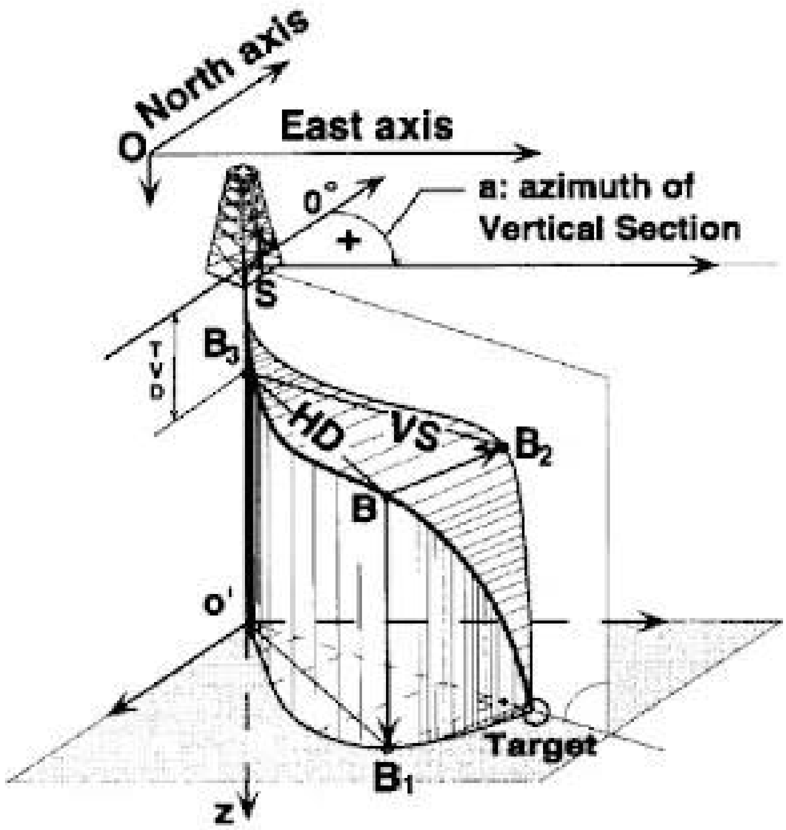


Figure 5.4 Directinal drilling

"a" represents the vertical section plane's azimuth in degrees. It is measured from the North Direction (geographic) in a horizontal plane starting at 0° and going all the way to 360°. (clockwise from North axis).

We have to find pressure ad given points also for directional wells. We determine 3 point

which are 50 ft above final depth;650 ft above and 1200 ft above final depth. Our final

depth D=7830 ft, so our determined points are TVD_1_new=7780 ft,

TVD_2_new=7180ft ; TVD_3_new=6630ft.

Again for each given flow rate we calculate P5 (I called them as P_TVD_1_new, P_TVD_2_new, P_TVD_3_new corresponsible)for our determined points . Then we have to determine pressure difference between them (delta_P_TVD_1_new=P_TVD_1_new-P_TVD_2_new, delta_P_TVD_2_new=P_TVD_1_new- P_TVD_3_new ,delta_P_TVD_3_new=P_TVD_2_new-P_TVD_3_new)

We also calculated Equivalent circulation density and Bottom Hole pressure for each.

CHAPTER 6

RESULTS AND CONCLUSION

Our model & reality
We calculated delta P between P1, P2and P3 . In reality we have sensors which are able to measure pressure as well.
So there is pressure difference in reality also. If delta P real= delta P model , that is good.
If there is deviation we can monitor and inform it as solid concentration increases.
Here , in figure shown our pressure window and also P 3points which we chose 50 ft above final depth;650 ft above and 1200 ft above final depth.

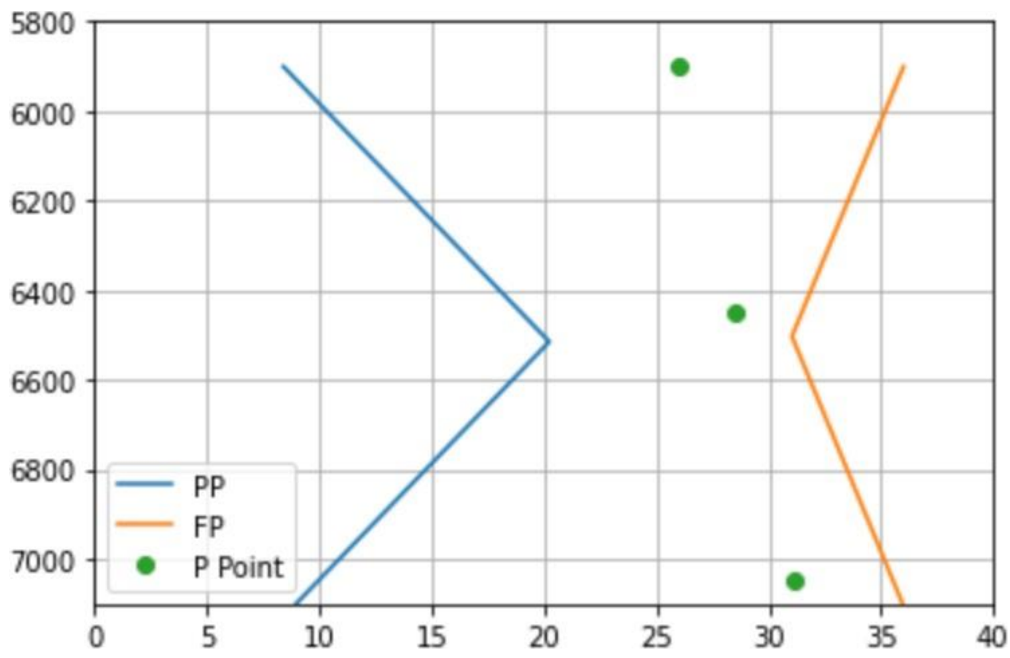


Figure 6.1. Pressure window

We have hydraulic model. Whatever points along string we can calculate pressure. In a case if there are pressure sensors along string and devices like ASM if they are calculating pressure as well, we can compare the model and the real measurements . If they are equal then model works fine and there is no problem related to pressure in our well, or if there is change in delta P model and reality , so we can find out some issue. For example pack off or high concentration.

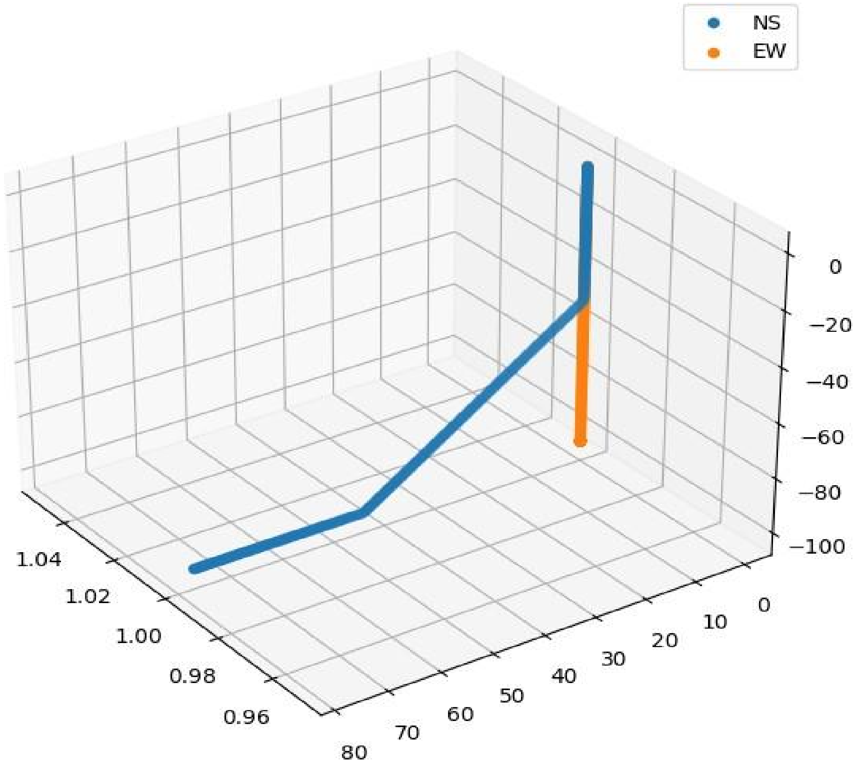


Figure 6.2 pressure profile

Pros of our research, We are working on the digitization by creating a coding package that goes towards automating and digitizing the drilling process. Our ultimate goal is to conduct drilling operations remotely. And also the accuracy of the operation is increased. Overall we see the time and that will help reduce the carbon footprint in the next phase. The negative part of our work is that we involve the automation process.
We must take into account all the parameters. We work on assumptions. Assumptions lead to results. Our coding package may not be as accurate and it may also be misleading in detecting issues, we may or may not detect something else.
Every assumption we make affects the outcome. If we reduce the number of assumptions, our model will definitely be closer to the real case. But what follows is that if we reduce the number of assumptions and bring more parameters into our model, our model becomes complex, the running time becomes longer. But this needs to be updated in future work.

As a first assumption we have assumed that the hydraulic model is a power law, which in reality is not always the case. We did not include the temperature in our calculations in the model, this affects our result. The influence of density was also not taken into account. When we pump mud we know the density that is in the mud tank, but when the mud is mixed with cut the density of the mud changes. We assumed that the mud density is constant. The other assumption is the borehole profile

We have assumed in all our calculations that the borehole is 8 ½ inches, which in reality is not the case. We have washouts, errors that also affect the measurements when the model is calculated. We first assumed only vertical wells, then directional wells. All of these were functions that didn't take any calculations into account, making them more complicated. So we started making a simple model just to test if the system works. In future work we can also include these functions.

If we see differences when comparing pressure differences, one of the expenses is the reduction in concentration. It could be another reason as well, but in this work we will focus on what is one of the main features we are looking for. The difference also depends on the bit type. If we drill with PDC bits and include power, the cutting concentration may not be correct. If we drill with a tricone bit , whose cuttings are larger, this could be the case. The belief that there is more cutting as we drill, and our goal is to identify the concentration of cutting that leads to packing. To that end, this method builds, that's the output. For the next step we can bring in more parameters and also update the model and also use machine learning

APPENDIX A

APPENDIX

```
import pip
pip.main(["install", "openpyxl"])
pip.main(["install", "sympy"])
pip.main(["install", "xlsxwriter"])
pip.main(["install", "matplotlib"])
pip.main(["install", "numpy"])

import pandas as pd

well_data = pd.ExcelFile('Well_Data.xlsx')
string_data = pd.read_excel(well_data, 'String_Data')
survey_data = pd.read_excel(well_data, 'Survey_Data')

pwd_data = pd.ExcelFile('Simulated_PWD_Data.xlsx')
pwd_table = pd.read_excel(pwd_data, 'Sheet1')
```

Q (gpm)	**SPP (psi)**	**MD bit (ft)**	**TVD bit (ft)**	**simulated pressure at bit by power law model (psi)**	**MD Borehole (ft)**	**TVD Borehole (ft)**	**simulated pressure at bit by Herschel Bulkley model (psi)**	
0	474.031687	1402.004670	7849.07068	6355.03452	3505.652677	7849.07068	6355.03452	3434.385681
1	473.849437	1402.081482	7849.10349	6355.03452	3503.727704	7849.10349	6355.03452	3432.364832
2	473.982378	1402.155340	7849.10349	6355.03452	3501.945749	7849.10349	6355.03452	3430.494235
3	474.110302	1402.226411	7849.10349	6355.03452	3500.497555	7849.10349	6355.03452	3428.963690

Q (gpm)	SPP (psi)	MD bit (ft)	TVD bit (ft)	simulated pressure at bit by power law model (psi)	MD Borehole (ft)	TVD Borehole (ft)	simulated pressure at bit by Herschel Bulkley model (psi)	
4	474.233488	1402.160507	7849.13630	6355.03452	3499.547331	7849.13630	6355.03452	3427.936567
...	...	...	...	...	...	...	...	...
64759	523.593916	1661.043080	8206.37158	6355.10014	3526.933466	8206.37158	6355.10014	3440.017406
64760	523.496792	1660.958078	8206.37158	6355.10014	3525.193473	8206.37158	6355.10014	3438.183863
64761	523.396003	1660.979370	8206.37158	6355.10014	3525.833865	8206.37158	6355.10014	3438.877014
64762	523.599519	1661.001481	8206.37158	6355.10014	3526.897566	8206.37158	6355.10014	3439.997367
64763	523.811016	1661.308949	8206.37158	6355.10014	3525.346156	8206.37158	6355.10014	3438.342229

64764 rows × 8 columns

```
L_c=2550.0
L_dp =6480.0
L_dc = 620.0


OD_c=13.725
OD_dp=5
OD_dc=8


ID_c=12.565
ID_dp=4.276
ID_dc=2.87
ID = 12.25



RHO = 8.824
PV = 12.0
YP = 12.0
Q=700
ID_list = [ID_c, ID_dp, ID_dc]
theta300=PV + YP
theta600=theta300 +PV
```

```
print('theta300',theta300)
print('theta600',theta600)

theta300 24.0
theta600 36.0

import math
def pressure_drop_2 (k, n, Q, ID, PV):

   # Critical velocity
   V_c = (((5.82 * ((10.0)**4) * k) / RHO) ** (1/(2 - n))) \
      * ((1.6/ID_dp)*((3 * n+1) / 4 * n)) ** (n / (2-n))

   # Average Velocity
   V_avg = 24.5 * Q / (ID_dp **2)
   if(V_avg > V_c):  # flow is turbulent
      P = (8.91 * (10**(-5)) * (RHO ** 0.8) * (Q ** 1.8) \
         * ((PV ** 0.2) * L_dp))/(ID_dp ** 4.8)

   elif(V_avg < V_c): # flow is laminar
      P = (((1.6 * V_avg * (3*n+1))/(ID_dp * 4 * n)) ** n)\
         * (k * L_dp)/(300 * ID_dp)

   return P

def pressure_drop_3(k, n, Q, ID, PV):
    #Pressure losses inside drill collars(P3)
    V_c = (((5.82 * ((10.0)**4.0) * k) / (RHO)) ** \
        (1.0/(2.0 - n))) * (((1.6*(3.0 * n+1.0))/(ID_dc*4.0*n) )) ** (n / (2.0-n))

    V_avg = 24.5 * Q / (ID_dc**2)

    if(V_avg > V_c):  # flow is turbulent
        P3 = (((8.91 * (10**(-5)) * (RHO ** 0.8) * \
            (Q ** 1.8) * ((PV ** 0.2) * L_dc)))/(ID_dc ** 4.8))

    elif(V_avg < V_c): # flow is laminar
        P3 = (((1.6 * V_avg * (3.0*n+1.0))\
            /(ID_dc * 4.0 * n)) ** n) * (k * L_dc)/(300.0 * ID_dc)

    return P3

def pressure_drop_4(k, n, Q, ID_dc, PV):

   #Pressure losses around drill collars(P4)

   V_c=(((3.878*(10**(4.0))*k)/RHO)**(1.0/(2.0-n)))\
      * (((2.4*((2.0*n)+1.0))/((ID-OD_dc)*(3*n)))**(n/(2.0-n)))
```

```
    V_avg = 24.5 * Q / ((ID_dc **2.0)-(OD_dc**2.0))
    if(V_avg < V_c): # flow is laminar
        P4  = ((((2.4 * V_avg * (2.0*n+1.0))\
             /((ID - OD_dc) * 3.0 * n)) ** n)\
                * (k * L_dc)/(300.0 * (ID - OD_dc)))
    else:
        P4 = (8.91 * (10**(-5)) * (RHO ** 0.8) * (Q ** 1.8) \
            * ((PV ** 0.2) * L_dc))/((ID-OD_dc) ** 3.0)*((ID+OD_dc) ** 1.8)

    return P4
def pressure_drop_5(k, n, Q, ID, PV, L_c = L_c, L_dp = L_dp):
    #Annular losses (we determine in the open hole section and cased hole section)
    #Pressure losses around drillpipe. Cased hole section

    V_c = (((3.878 * ((10.0)**4.0) * k) / RHO) ** (1.0/(2.0 - n))) * \
        (((2.4/(ID_c-OD_dp))*((2.0 * n+1.0) / (3.0 * n))) ** (n / (2.0-n)))

    V_avg = 24.5 * Q / ((ID_c **2)-(OD_dp**2))

    if(V_avg < V_c): # flow is laminar
        P_a = (((2.4 * V_avg * (2*n+1))/((ID_c-OD_dp) * 3 * n)) ** n)\
            * (k * L_c)/(300 * (ID_c-OD_dp))
    else:
        P_a = (8.91 * (10**(-5)) * (RHO ** 0.8) * (Q ** 1.8) * \
            ((PV ** 0.2) * L_c))/((ID_c-OD_dp) ** 3.0)*((ID_c+OD_dp) ** 1.8)

    #Open hole section
V_c = (((3.878 * ((10.0)**4) * k) / RHO) ** (1/(2 - n))) * \
        (((2.4/(ID-OD_dp))*((2 * n+1) / (3 * n))) ** (n / (2-n)))
    V_avg = 24.5 * Q / ((ID_c **2)-(OD_dp**2))
    if(V_avg < V_c): # flow is laminar
        P_b = (((2.4 * V_avg * (2*n+1))/((ID-OD_dp) * 3 * n)) ** n) \
          * (k * L_dp)/(300 * (ID_c-OD_dp))
    else:
        P_b = (8.91 * (10**(-5)) * (RHO ** 0.8) * (Q ** 1.8) * \
            ((PV ** 0.2) * L_c))/((ID_c-OD_dp) ** 3.0)*((ID_c+OD_dp) ** 1.8)
    #Total pressure loss around drillpipe (P5)
    P5 = P_a +P_b

    return P5

Q=700
# n is power law index
n = 3.32 * math.log(theta600/theta300,10)
print('n',n)
# consistency index
k = theta300/((511.0) ** n)
```

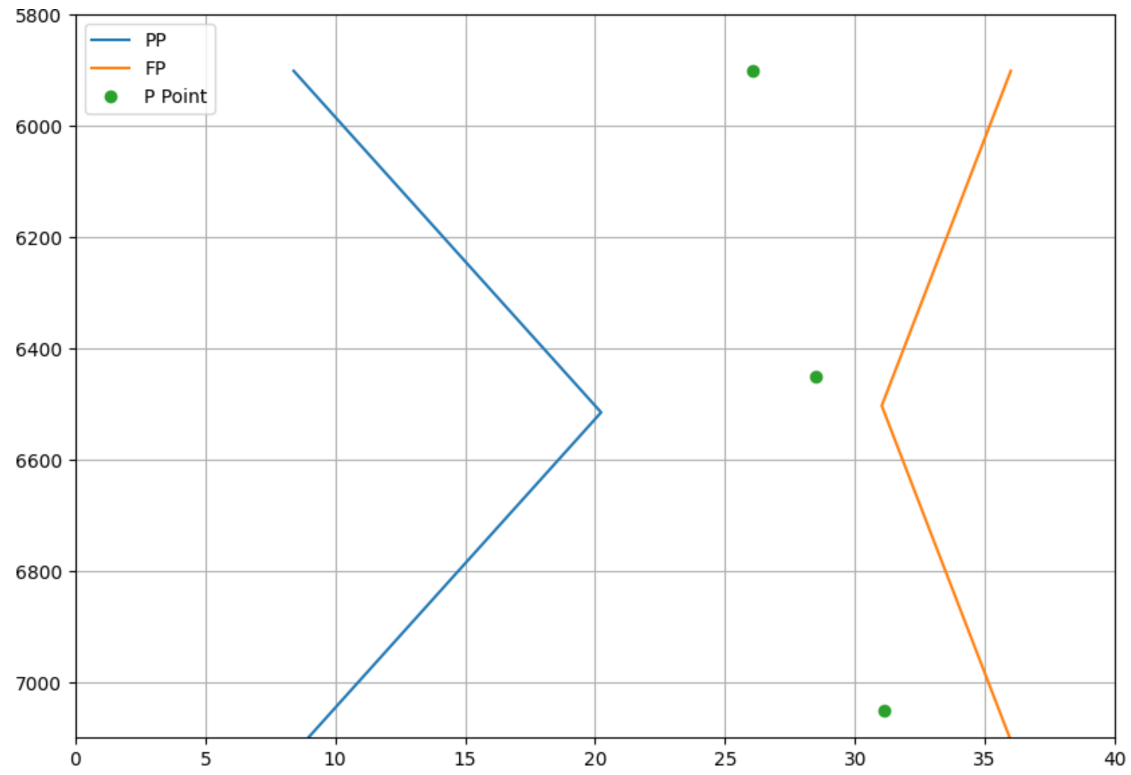
```
print('k',k)
list_for_table = []
header_table = ['Q', 'P1','P2','P3','P4','P5', 'P', 'ECD', 'BHP']  # to store all results



#surface losses
P1 = 4.2*(10.0**(-5))*(RHO**(0.8))*(Q**(1.8))*(PV**(0.2))
print('P1',P1)
#pressure losses inside drillpipe(P2)
P2 = pressure_drop_2(k, n, Q, ID, PV)

#Pressure losses inside drill collars(P3)
P3 = pressure_drop_3(k, n, Q, ID, PV)

#Pressure losses around drill collars(P4)
P4 = pressure_drop_4(k, n, Q, ID, PV)


#Pressure losses around drillpipe. Cased hole section
P5 = pressure_drop_5(k, n, Q, ID, PV)

ECD = ((P5/(0.052 * pwd_table['TVD bit (ft)']))+ RHO)
BHP = (0.052 * RHO * pwd_table['TVD bit (ft)'])+ECD

P = P1 + P2 + P3 + P4 + P5

for i in range(len(ECD)):
    list_for_table.append([Q, P1, P2, P3, P4, P5, P, ECD[i], BHP[i]])

pressure_losses_table = pd.DataFrame(list_for_table, columns=header_table)

n 0.5846229800648617
k 0.6263342252163234
P1 52.094804334237494


#pressure_table.to_excel("pack_off_detection.xlsx", sheet_name="Pressure_losses")


D=7100
TVD_1=7050
TVD_2=6450
TVD_3=5900


list_for_table = []
header_table = ['Q', 'P_TVD_1', 'P_TVD_2','P_TVD_3','delta_P_TVD_1',\
```

```
            'delta_P_TVD_2', 'delta_P_TVD_3'] # to store all results

for i in range(150):
    Q = pwd_table['Q (gpm)'][i]

    P_TVD_1 = pressure_drop_5(k, n, Q, ID, PV, L_c=TVD_1, L_dp=TVD_1 )
    P_TVD_2 = pressure_drop_5(k, n, Q, ID, PV, L_c=TVD_2, L_dp=TVD_2 )
    P_TVD_3 = pressure_drop_5(k, n, Q, ID, PV, L_c=TVD_3, L_dp=TVD_3 )


    delta_P_TVD_1=P_TVD_1- P_TVD_2
    delta_P_TVD_2=P_TVD_1- P_TVD_3
    delta_P_TVD_3=P_TVD_2-P_TVD_3


#ECD = ((P5/(0.052 * pwd_table['TVD bit (ft)']))+ RHO)
#BHP = (0.052 * RHO * pwd_table['TVD bit (ft)'])+ECD

list_for_table.append([Q, P_TVD_1, P_TVD_2, P_TVD_3,\
                       delta_P_TVD_1, delta_P_TVD_2, delta_P_TVD_3, ])
p_tvd_table = pd.DataFrame(list_for_table, columns=header_table)
#dataframe.to_excel("pack_off_detection.xlsx", sheet_name='P_TVD')


def dfs_tabs(df_list, sheet_list, file_name):
  writer = pd.ExcelWriter(file_name,engine='xlsxwriter')
  for dataframe, sheet in zip(df_list, sheet_list):
    dataframe.to_excel(writer, sheet_name=sheet, startrow=0 , startcol=0)
  writer.save()

dfs = [pressure_losses_table, p_tvd_table]
sheets = ['Pressure_losses','P_TVD' ]

dfs_tabs(dfs, sheets, 'pack_off_detection.xlsx')


graph_data = pd.ExcelFile('graph_data.xlsx')
graph_table = pd.read_excel(graph_data, 'Sheet2')
graph_table
```

	Q	TVD	pore_pressure	frac_pressure	Unnamed: 4	Unnamed: 5	Unnamed: 6
0	700	5901.000000	8.400000	36.000000	NaN	NaN	NaN
1	700	5905.013378	8.477333	35.966887	NaN	36-31	5.000000
2	700	5909.026756	8.554667	35.933775	NaN	29-31	0.033113
3	700	5913.040134	8.632000	35.900662	NaN	NaN	NaN

Q	TVD	pore_pressure	frac_pressure	Unnamed: 4	Unnamed: 5	Unnamed: 6	
4	700	5917.053512	8.709333	35.867550	NaN	NaN	NaN
...	...	...	...	...	...	...	...
296	700	7088.959867	9.173333	35.867550	NaN	NaN	NaN
297	700	7092.973245	9.096000	35.900662	NaN	NaN	NaN
298	700	7096.986623	9.018667	35.933775	NaN	NaN	NaN
299	700	7101.000001	8.941333	35.966887	NaN	NaN	NaN
300	700	7105.013379	8.864000	36.000000	NaN	NaN	NaN

```
D=7100
TVD_1=7050
TVD_2=6450
TVD_3=5900

for i in range(1):
    Q = pwd_table['Q (gpm)'][i]

    P_TVD_1 = pressure_drop_5(k, n, Q, ID, PV, L_c=TVD_1, L_dp=TVD_1 )
    P_TVD_2 = pressure_drop_5(k, n, Q, ID, PV, L_c=TVD_2, L_dp=TVD_2 )
    P_TVD_3 = pressure_drop_5(k, n, Q, ID, PV, L_c=TVD_3, L_dp=TVD_3 )

TVD = graph_table['TVD']
pore_p = graph_table['pore_pressure']
frac_p = graph_table['frac_pressure']

import matplotlib.pyplot as plt

plt.plot(pore_p, TVD, label = "PP" )
plt.plot(frac_p, TVD, label = "FP")
plt.plot([P_TVD_1, P_TVD_2, P_TVD_3], [TVD_1, TVD_2, TVD_3],\
     'o', label = "P Point")
plt.legend()
plt.grid()
plt.ylim(7100.0 , 5800.0)
plt.xlim(0.0 , 40.0)

plt.rcParams["figure.figsize"] = (10,7)
plt.show()
```




```
#Directional drilling

graph_data = pd.ExcelFile('graph_dadata.xlsx')
graph_table = pd.read_excel(graph_data, 'Sheet1')
graph_table['MD']
```

0 0.0 1 0.5 2 1.0 3 1.5 4 2.0 ....295 147.5 296 148.0 297 148.5 298 149.0 299 149.5 Name: MD, Length: 300, dtype: float64

```
import numpy as np
import math
alpha = np.zeros(300)
betta = np.zeros(300)
DL = np.zeros(300)
RF = np.zeros(300)
T_V_D = np.zeros(300)
NS =  np.zeros(300)
EW = np.zeros(300)
dir = np.zeros(300)
CL_D = np.zeros(300)
V_D = np.zeros(300)
dog_leg = np.zeros(300)
```

```
MD = graph_table['MD']
azimuth = graph_table['azimuth']
incl = graph_table['incl']
for i in range(1, 300):

    # alpha
    alpha[i] = incl[i]/57.2957795

    #betta
    betta[i] = azimuth[i]/57.2957795

    #DL
    DL[i] =math.acos(round(math.cos(alpha[i])*math.cos(alpha[i-1])+\
        math.sin(alpha[i])*\
        math.sin(alpha[i-1])*math.cos(betta[i]- betta[i-1]), 5))

    #RF
    if(DL[i] == 0):
        RF[i] = 1
    else:
        RF[i] = math.tan(DL[i]/2)/(DL[i]/2)

    #T_V_D
    # #for directional wells TVD and Measured depth are not same so we have to calculate it
    T_V_D [i]=(((MD[i]-MD[i-1])/2)*(math.cos(alpha[i])+\
            math.cos(alpha[i-1])) *RF[i])+T_V_D[i-1]
    #print(MD[i])
    #for sections
    #North_South
    NS[i] = NS[i-1] + ((MD[i] - MD[i-1])/2) * (math.sin(alpha[i-1])\
         * math.cos(betta[i-1]) + math.sin(alpha[i]) * math.cos(betta[i])) * RF[i]


#East West
    EW[i] = EW[i-1] + ((MD[i] - MD[i-1])/2) * (math.sin(alpha[i-1])\
         * math.sin(betta[i-1]) + math.sin(alpha[i]) * math.sin(betta[i])) * RF[i]

    # dir
    if(NS[i]==0 and EW[i] == 0):
        dir[i] = 0
    else:
        if(NS[i]>0):
            if(EW[i]>0):
                dir[i] = math.atan(EW[i]/NS[i]) * 57.29577951
            else:
                dir[i] = 360 + math.atan(EW[i]/NS[i]) * 57.29577951
        else:
```

```
            dir[i] = 180 + math.atan(EW[i]/NS[i]) * 57.29577951


#closure drift
    CL_D[i] = math.sqrt(EW[i] * EW[i] + NS[i] * NS[i])

    #vertical drift
    V_D[i] = CL_D[i] * math.cos((200-dir[i])/57.29577951)

    #dog leg
    dog_leg[i] = (math.acos(math.sin(incl[i-1]/57.3) * math.sin(incl[i]/57.3)\
         * math.cos((azimuth[i] - azimuth[i-1])/57.3) \
        + (math.cos(incl[i-1]/57.3)*math.cos(incl[i]/57.3)))*57.3) \
        * (100/(MD[i] - MD[i-1]))

dataf = pd.DataFrame({'alpha': alpha,
            'betta': betta,
            'DL': DL,
            'RF': RF,
            'T_V_D': T_V_D,
            'NS': NS,
            'EW': EW,
            'dir': dir,
            'closure': CL_D,
            'Vertical': V_D,
            'dog_leg': dog_leg})
dataf
```

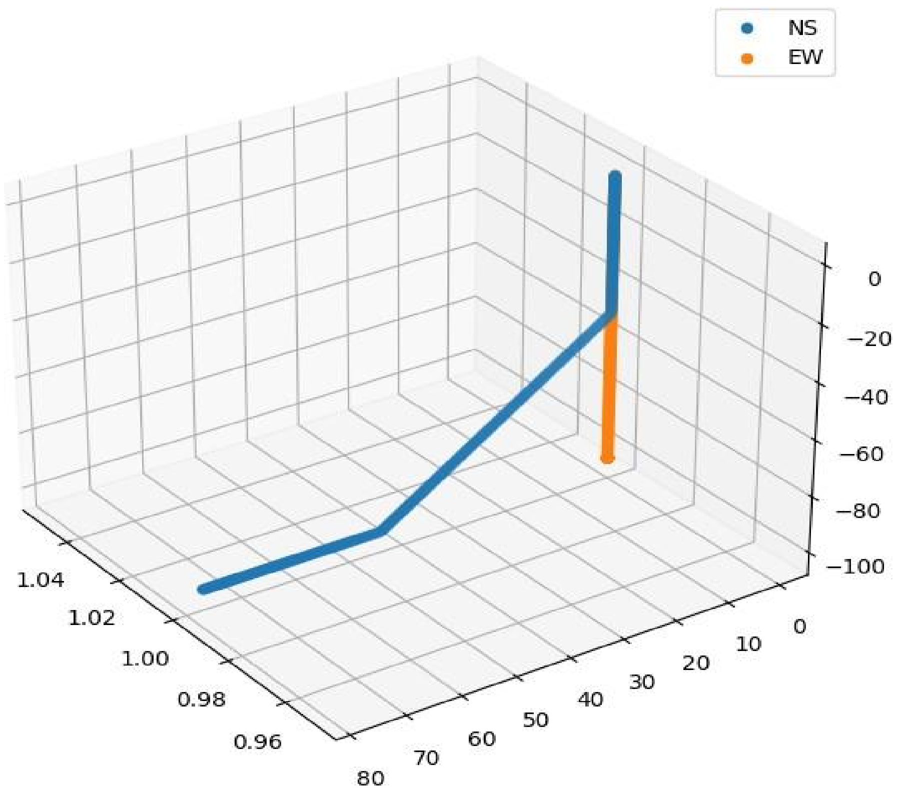
alpha	betta	DL	RF	T_V_D	NS	EW	dir	closure	Vertical	dog_leg	
0	0.000000	0.0	0.0	0.0	0.000000	0.000000	0.0	0.0	0.000000	0.000000	0.000000
1	0.000000	0.0	0.0	1.0	0.500000	0.000000	0.0	0.0	0.000000	-0.000000	0.000000
2	0.000000	0.0	0.0	1.0	1.000000	0.000000	0.0	0.0	0.000000	-0.000000	0.000000
3	0.000000	0.0	0.0	1.0	1.500000	0.000000	0.0	0.0	0.000000	-0.000000	0.000000
4	0.000000	0.0	0.0	1.0	2.000000	0.000000	0.0	0.0	0.000000	-0.000000	0.000000
...	...	...	...	...	...	...	...	...	...	...	...
295	1.570796	0.0	0.0	1.0	100.751494	74.885235	0.0	360.0	74.885235	-70.369103	0.000171

	alpha	betta	DL	RF	T_V_D	NS	EW	dir	closure	Vertical	dog_leg
296	1.570796	0.0	0.0	1.0	100.751494	75.385235	0.0	360.0	75.385235	-70.838949	0.000171
297	1.570796	0.0	0.0	1.0	100.751494	75.885235	0.0	360.0	75.885235	-71.308795	0.000171
298	1.570796	0.0	0.0	1.0	100.751494	76.385235	0.0	360.0	76.385235	-71.778641	0.000171
299	1.570796	0.0	0.0	1.0	100.751494	76.885235	0.0	360.0	76.885235	-72.248488	0.000171

300 rows × 11 columns

```
#pressure determination at given points
D=7830
TVD_1_new=7780
TVD_2_new=7180
TVD_3_new=6630


list_for_table = []
header_table = ['Q',
             'P_TVD_1_new',
             'P_TVD_2_new',
             'P_TVD_3_new',
             'delta_P_TVD_1_new',
             'delta_P_TVD_2_new',
             'delta_P_TVD_3_new']  # to store all results

for i in range(150):
    Q = pwd_table['Q (gpm)'][i]

    P_TVD_1_new = pressure_drop_5(k, n, Q, ID, PV, L_c=TVD_1_new, L_dp=TVD_1_new )
    P_TVD_2_new = pressure_drop_5(k, n, Q, ID, PV, L_c=TVD_2_new, L_dp=TVD_2_new )
    P_TVD_3_new = pressure_drop_5(k, n, Q, ID, PV, L_c=TVD_3_new, L_dp=TVD_3_new )



    delta_P_TVD_1_new=P_TVD_1_new- P_TVD_2_new
    delta_P_TVD_2_new=P_TVD_1_new- P_TVD_3_new
    delta_P_TVD_3_new=P_TVD_2_new-P_TVD_3_new



    ECD = ((P5/(0.052 * pwd_table['TVD bit (ft)']))+ RHO)
```

```
    BHP = (0.052 * RHO * pwd_table['TVD bit (ft)'])+ECD

    list_for_table.append([Q, P_TVD_1_new, P_TVD_2_new, \
        P_TVD_3_new,delta_P_TVD_1_new, delta_P_TVD_2_new, \
            delta_P_TVD_3_new])
    p_tvd_table_new = pd.DataFrame(list_for_table, columns=header_table)
    #dataframe.to_excel("pack_off_detection.xlsx", sheet_name='P_TVD_new')


def dfs_tabs(df_list, sheet_list, file_name):
  writer = pd.ExcelWriter(file_name,engine='xlsxwriter')
  for dataframe, sheet in zip(df_list, sheet_list):
    dataframe.to_excel(writer, sheet_name=sheet, startrow=0 , startcol=0)
  writer.save()

dfs = [pressure_losses_table, p_tvd_table, dataf, p_tvd_table_new]
sheets = ['Pressure_losses','P_TVD', 'directional_drilling', 'P_TVD_New']

dfs_tabs(dfs, sheets, 'pack_off_detection.xlsx')

import matplotlib.pyplot as plt


ax = plt.axes(projection='3d')

# Data for a three-dimensional line
xline = np.ones(len(NS))
yline  = NS
zline = -T_V_D
ax.scatter3D(xline, yline, zline, label = "NS")

xline = np.ones(len(NS))
yline = EW
zline = -T_V_D
ax.scatter3D(xline, yline, zline, label = "EW")

ax.view_init(30, 145)
plt.legend()

plt.rcParams["figure.figsize"] = (10,7)
plt.show()
```


NS
EW
0
−20
−40
−60
−80
−100
1.04
1.02
1.00
0.98
0.96
0
10
20
30
40
50
60
70
80

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