Master's thesis

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

Salar Hafezi

Real-time detection of drilling problems & issues during drilling by listing & using their signs both on the surface and downhole

Master's thesis in Petroleum Engineering
Supervisor: Behzad Elahifar
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Abstract

The oil and gas industry is widely acknowledged as one of the most perilous sectors worldwide. The process of extracting hydrocarbons from underground reservoirs carries significant risks and uncertainties. It is therefore crucial to identify the underlying causes of these risks and uncertainties. The majority of such challenges are encountered during drilling operations. Consequently, drilling problems serve as an invaluable benchmark for various disciplines within petroleum engineering. However, the key to achieving successful drilling objectives lies in designing drilling programs that anticipate potential issues. The more comprehensive the list of problems, the more accurate the solutions can be.

The most effective approach is to proactively avoid scenarios where problems may arise. This preventive approach promotes safer and more cost-effective drilling strategies. It is widely recognized that even a single incident resulting in loss of human life, environmental catastrophe, or damage to rig infrastructure can have far-reaching consequences for the entire petroleum industry. Some common drilling problems include drillpipe sticking, stuck pipe, drillstring failures, wellbore instabilities, hole deviation and well path control, mud contamination, kicks, hazardous and shallow gas release, lost circulation, formation damage, loss of equipment, personnel, and communications. Additionally, specific challenges arise in slim hole drilling, coiled tubing drilling, extended reach drilling, and under-balance drilling, among others. As the saying goes, ”prevention is better than cure.” Hence, the motto should be to drill safely, avoiding accidents, incidents, and harm to the environment while minimizing costs. Sustainable drilling practices that prioritize the reduction of drilling problems and associated expenses should be the utmost priority.

The aim of this program is to create a list of all the problems that could arise during drilling as well as their signs both on the surface and downhole, in order to determine them using those signs and by the means of filtration, the complete method and the theory of which will be discussed in detail in a subsequent section.

Sammendrag

Olje- og gassindustrien er allment anerkjent som en av de farligste sektorene globalt. Prosessen med å utvinne hydrokarboner fra underjordiske reservoarer innebærer betydelige risikoer og usikkerheter. Det er derfor avgjørende å identifisere de underliggende årsakene til disse risikoene og usikkerhetene. Flertallet av slike utfordringer oppstår under boreoperasjoner. Følgelig fungerer boreproblemer som en uvurderlig referanse for ulike disipliner innen petroleumsteknikk. Likevel ligger nøkkelen til å oppnå vellykkede boremål i utformingen av boreprogrammer som tar hensyn til potensielle problemer. Jo mer omfattende listen over problemer er, desto mer nøyaktige kan løsningene være.

Den mest effektive tilnærmingen er å proaktivt unngå scenarier der problemer kan oppstå. Denne forebyggende tilnærmingen fremmer sikrere og mer kostnadseffektive borestrategier. Det er allment anerkjent at selv en enkelt hendelse som resulterer i tap av menneskeliv, miljøkatastrofe eller skade på rigginfrastrukturen kan ha vidtrekkende konsekvenser for hele petroleumsindustrien. Noen vanlige boreproblemer inkluderer fastkjøring av borestrengen, fastklemt borestreng, feil på borestrengen, ustabiliteter i brønnbanen, avvik fra brønnen og kontroll av brønnbanen, forurensning av borevæske, utblåsninger, farlig og grunn gassutslipp, sirkulasjonstap, formasjonsskader, tap av utstyr, personell og kommunikasjon. I tillegg oppstår spesifikke utfordringer ved slankebrønner, coiled tubing-boring, utvidet rekkevidde-boring og underbalanseboring, blant andre. Som ordtaket sier, ”forebygging er bedre enn helbredelse”. Derfor bør mottoet være å bore trygt, unngå ulykker, hendelser og skade på miljøet samtidig som man minimerer kostnadene. Bærekraftige borepraksiser som prioriterer reduksjon av boreproblemer og tilhørende utgifter bør være den øverste prioriteringen.

Målet med dette programmet er å lage en liste over alle problemene som kan oppstå under boring, samt deres tegn både på overflaten og ned i brønnen, for å identifisere dem ved hjelp av disse tegnene og ved hjelp av filtrering. Den fullstendige metoden og teorien vil bli diskutert i detalj i en senere seksjon.

Preface

This master's thesis is submitted as part of the requirements for the MSc in Petroleum Engineering at the Norwegian University of Science and Technology (NTNU), Department of Geoscience and Petroleum (IGP), Faculty of Engineering (IV).

The thesis is focused on the drilling problems encountered in the oil and gas industry, and the importance of designing drilling programs based on anticipation of potential problems.

The prevention of drilling problems is crucial to ensure safe and cost-effective drilling operations.

This thesis provides a comprehensive list of drilling problems, their signs, and a filtration-based program for their identification.

Acknowledgements

The research topic for this thesis was decided in consultation with Behzad Elahifar, my supervisor, who has provided invaluable guidance and support throughout this project. I am deeply grateful to him for his expertise and encouragement.

I would also like to express my sincere appreciation to my mother who taught me to enjoy learning as well as my wonderful sister for her unwavering support and motivation during the writing of the thesis. Special thanks to my father for helping me step into his shoes by giving me important tips and advises that undeniably shaped my understanding of the Petroleum industry.

I am grateful to Sigbjørn Sangesland, the professor whose consultation was necessary for me to choose this topic, and organized a variety of drilling courses that enhanced my understanding of the process of drilling.

I hope that this thesis will contribute to the ongoing efforts to improve drilling operations in the petroleum industry.

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List of Abbreviations

API American Petroleum Institution

ASM Along String Measurements

BHA Bottomhole Assembly

bit/sec Bits per Second

BSEE Bureau of Safety and Environmental Enforcement

DSA Drilling Systems Automation

EKD Early Kick Detection

EPWD Engineering Parameters While Drilling

ERD Extended Reach Drilling

ft Feet

GUI Graphical User Interface

HSE Health, Safety, and Environmental

HST High-Speed Telemetry

IADC International Association of Drilling Contractors

IADC International Association of Drilling Contractors

kbps Kilobits per second

LCM Lost Circulation Materials

LWC Loss of Well Control

LWD Logging While Drilling

Mbit/sec Megabits per Second

MOP Margin of Overpull

MWD Measuring While Drilling

NPT Nonproductive Time

PCD Polycrystalline Diamond

PDC Polycrystalline Diamond Compact

PIL Python Imaging Library

ppg Pounds per Gallon

psi Pounds per Square Inch

PWD Pressure While Drilling

RC Roller Cone

ROP Rate of Penetration

RPM Rotations per Minute

RSS Rotary Steerable Systems

SCC Stress Corrosion Cracking

SPE	Society of Petroleum Engineers
SPP	Stand Pipe Pressure
TVD	Total Vertical Depth
UKF	Unscented Kalman Filter
VIV	Vortex-Induced Vibration
WDP	Wired Drillpipe
WOB	Weight on Bit

1 Introduction

The oil and gas industry is renowned for being one of the most hazardous industries worldwide. The risks and uncertainties associated with extracting hydrocarbons from underground reservoirs make it crucial to identify the root causes of the challenges that arise in the drilling process. While drilling problems can cause significant delays, unexpected costs, and environmental disasters, they can also be avoided by designing drilling programs based on the anticipation of potential drilling problems.

This thesis aims to provide a comprehensive list of drilling problems that could arise during the drilling process and their corresponding signs, both on the surface and downhole. The identification of drilling problems through their signs is crucial to prevent major incidents such as loss of human life, environmental disasters, and loss of equipment. This thesis will explore the methods and theories used to detect drilling problems, and implement them into one, single user-friendly application.

1.1 Motivation

The oil and gas industry is an integral part of the global economy, powering transportation, industry, and residential and commercial energy needs. However, it is also recognized as one of the most hazardous industries on earth. Extracting hydrocarbon from an underground reservoir is a complex and challenging task that involves numerous risks and uncertainties. These risks not only pose a threat to the workers and the environment but also have a profound impact on the financial health of the industry as a whole.

Given the complexity and inherent risks involved in drilling, it is crucial to understand the root causes of these risks and uncertainties. The majority of the risks and uncertainties related to this business are encountered while drilling. As a result, drilling problems offer an excellent benchmark for other practices in petroleum engineering as well as other disciplines.

It is well understood that even one occurrence of the loss of human life or an environmental disaster can have a profound effect on the welfare of the entire petroleum industry. This underscores the importance of drilling operations being conducted in a sustainable fashion where the minimization of drilling problems and costs has to have the top priority.

In addition, the oil and gas industry is facing mounting pressure from the public, governments, and stakeholders to reduce its environmental impact. Climate change and sustainability have become major issues in the global discourse, and the oil and gas industry has a significant role to play in addressing these concerns. By minimizing drilling problems and costs, companies can not only improve their financial performance but also reduce their environmental footprint.

Therefore, the motivation behind this thesis is to develop a program using comprehensive list of potential drilling problems and their associated signs both on the surface and downhole, in order to detect drilling problems as early as possible. By doing so, drilling engineers and operators can anticipate these issues and develop effective mitigation strategies. This will not only enhance the safety and sustainability of drilling operations but would also improve the financial performance of the industry as a whole.

1.2 Goals & Objectives

The primary goal of this thesis is to develop a comprehensive list of potential drilling problems and their associated signs, both on the surface and downhole. This will be achieved by analyzing drilling data, literature review, and case studies from the oil and gas industry.

To accomplish this goal, the following objectives have been set:

1. Identify the major drilling problems: The first objective is to identify the major drilling problems that can occur during drilling operations. This will involve an extensive review of literature, case studies, and drilling data to identify the most common and critical drilling problems.
2. Determine the signs of drilling problems: Once the major drilling problems have been identified, the next objective is to determine the signs of these problems, both on the surface and downhole. This will involve analyzing drilling data, logs, and other diagnostic tools to identify the signs of drilling problems such as stuck pipe, lost circulation, and wellbore instability.
3. Develop a comprehensive list of drilling problems and their signs: The third objective is to develop a comprehensive list of potential drilling problems and their associated signs. This list will serve as a tool for the next goal.
4. Develop a python based application in order to detect drilling problems in a short span of time: The fourth objective is to develop a program based on the comprehensive list of potential drilling problems and their associated signs.

By achieving these objectives, this thesis aims to provide drilling engineers and operators with a comprehensive guide to anticipate and mitigate drilling problems, improve drilling performance, and enhance safety and sustainability.

2 Theory

The program was compiled by listing a number of most detrimental drilling problems, which are the most prevalent during drilling. For a better understanding of how the filtration works, a good knowledge of those problems is necessary. Hence, this part is dedicated to investigating those problems thoroughly.

2.1 Sour Gas Bearing Zones

During drilling and workover operations, the consequences of leaks with sour gas or crude may be devastating. Drilling H2S-bearing formations poses one of the most difficult and dangerous problems to humans and equipment. Personnel can be injured or even killed by relatively low concentrations of H2S in a very short period of time. Equipment can experience terrible failure due to H2S gas-induced material failure. This risk depends primarily on the H2S content with the formation fluids, formation pressure, and the production flow rate, and therefore the SPP and downhole pressure will increase, the return rate will as well and subsequently will the pit volume. The pump rate will, however go down. This information is used to assess the level of risk from the presence of H2S. In addition, if this risk is known or anticipated, there are very specific requirements to abide by in accordance to International Association of Drilling Contractors (International Association of Drilling Contractors (IADC)) rules and regulations. All information will ultimately lead to the requirement for special equipment, layout, and emergency procedures for drilling and/or workover operations.

2.2 Shallow Gas-Bearing Zones

Shallow gas-bearing zone is defined as any hydrocarbon-bearing zone, which may be encountered at a depth close to the surface or mudline. In generally, it is not possible to close in and contain a gas influx from a shallow zone because weak formation integrity may lead to breakdown and broaching to surface and/or mudline. This situation is particularly hazardous when drilling operations continue from a fixed installation or jackup rig. Shallow gas-bearing zones are usually in a pressured condition. However, the effective increase in pore pressure due to gas gradient can lead to underbalance when a shallow gas zone is first penetrated.

Shallow gas may be encountered at any time in any region of the world. The only way to control this problem is that we should never shut in the well. It is also needed to divert the gas flow through a diverter system at the BOP. High-pressure shallow gas can be encountered at depths as low as a few hundred feet where the formation-fracture gradient is very low. The danger is that if the well is in shut-in condition, formation fracturing is more likely to occur. This will result in the most severe blowout problem, and ultimately an underground blow.

The identification and avoidance of shallow gas will be a principal objective in well planning and site survey procedures. All drilling programs shall contain a clear statement on the probability and risk of encountering shallow gas. This will be based on seismic survey and interpretation together with offset geological and drilling data. For onshore operations, consideration should be given for carrying out shallow seismic surveys in areas of shallow gas risk. In the absence of such surveys, assessment should be based on the exploration seismic data, historical well data, and the geological probability of a shallow gas trap. If shallow gas is a likelihood at the proposed drilling location, a shallow gas plan specific to company and the drilling contractor must be prepared prior to spudding the well. Special consideration should be given to: crew positions, training, evacuation plan, and emergency power shut down. For offshore operations, the presence of shallow gas can be extremely hazardous especially if no specific plan of action is prepared prior to spudding of the well. The driller will be instructed in writing on what action should be taken if a well kick should be noticed while drilling. The problem of drilling a shallow hole is that normal indications of a kick are not reliable. For example, penetration rates vary tremendously, and mud volume is continuously being added to the active system. The most reliable indicator is the differential flow sensor. Due to the difficulties of early detection and the depth of shallow gas reservoirs, reaction time is minimal. In such case, extreme caution, and alertness are required.

While drilling at shallow depth in a normally pressured formation, no indication of a gas pocket can be expected other than higher gas readings in the mud returns. Since the overbalance of the drilling fluid at shallow depths is usually minimal, pressure surges may cause an underbalanced situation which could result in a kick. Therefore, every attempt should be made to avoid swabbing. Some definitions are used to describe the risk in shallow gas assessment, such as i) high: an anomaly showing all of the seismic characteristics of a shallow gas anomaly, that ties to gas in an offset well, or is located at a known regional shallow gas horizon, ii) moderate: an anomaly showing most of the seismic characteristics of a shallow gas anomaly, but which could be interpreted not to be gas and, as such reasonable doubt exists for the presence of gas, iii) low: an anomaly showing some of the seismic characteristics of a shallow gas anomaly, but that is interpreted not to be gas although some interpretative doubt exists, and iv) negligible: either there is no anomaly present at the location or anomaly is clearly due to other, nongaseous, causes.

There are two factors that make shallow gas drilling a difficult challenge. First, unexpected pressure at the top of the gas-bearing zone, most often due to the “gas effect” dictated by zone thickness and/or natural dip, can be significant. This pressure is usually unknown, seismic surveys being often unable to give an idea either about thickness or in-situ gas concentration. In more complex situations, deep gas may migrate upwards along faults. For example, the influx in Sumatra could not be stopped even with 10.8 Pounds per Gallon (ppg) mud at very shallow depth because the bit had crossed a fault plane. Second, low formation fracture gradients are a predominant factor in shallow gas operations.

These two factors result in reduced safety margin for the driller. Minor hydrostatic head loss (e.g., swabbing, incorrect hole filling, cement slurry without gas-blocking agent), any error in mud weight planning (e.g., gas effect not allowed for), or any uncontrolled rate of penetration with subsequent annulus overloading will systematically and quickly result in well bore unloading. Shallow gas flows are extremely fast-developing events. There is a short transition time between influx detection and well unloading, resulting in much less time for driller reaction and less room for error. Poor quality and reliability of most kick-detection sensors worsen problems.

Previous history has disclosed the magnitude of severe dynamic loads applied to surface diverting equipment, and consequent high probability of failure. One of the associated effects is erosion, which leads to high potential of fire hazards and explosion from flow impingement on rig facilities.

The risk of cratering is a major threat against the stability of bottomsupported units. As it is impossible to eliminate them (i.e., most shallow gas-prone areas are developed from bottom supported units), emphasis should be put on careful planning and close monitoring during execution.

Shallow gas-bearing zone is defined as any hydrocarbon-bearing zone, which may be encountered at a depth close to the surface or mudline. Shallow gas-bearing zones are usually in a pressured condition. However, the effective increase in pore pressure due to gas gradient can lead to underbalance when a shallow gas zone is first penetrated. Judging by these effects, it can be said with certainty that the SPP and downhole pressure will certainly increase.

High-pressure shallow gas can be encountered at depths as low as a few hundred feet where the formation-fracture gradient is very low, and that is what differs it from sour gas bearing zone, which could occur at any depth.

2.3 Stacked Tools

Stacked tool is defined as “if a tool is lost or the drillstring breaks, the obstruction in the well is called junk or fish.” It cannot be drilled through if there is stacked tool. The preventive measure is to educate the crew. Special grabbing tools are used to retrieve the junk in a process called fishing. In extreme cases, explosives can be used to blow up the junk and then the pieces can be retrieved with a magnet.

Wellbore debris is responsible for many of the problems and much of the extra costs associated with producing wells, especially in extreme water depths and highly deviated holes. Even a small piece of debris at the right place at the wrong time can jeopardize well production. For this reason, debris management has become a major concern for oil and gas producers. Considering rig rates and completion equipment costs, debris removal is moving into the realm of risk management.

A clean wellbore is not only a prerequisite for trouble-free well testing and completion. It also helps ensure optimum production for the life of the well. Debris left in the wellbore can ruin a complex, multimillion-dollar completion. It can prevent a completion from reaching total depth. It will never reach an optimum production level. These issues are pushing the industry to create reliable, efficient systems for quickly ridding of wellbores harmful debris and larger pieces of junk.

Therefore, using this information, it can be concluded that as a result of this problem, the hook load will decrease. Also, it can be conjectured that the SPP and downhole pressures will decrease, the flow rate will increase, the return rate will face a sudden decrease and therefore the surface tank volume will decrease as well. Also, the ROP will decrease and so will the torque.

2.4 Resistant Beds Encountered

Once a resistant bed is encountered, it would result in dramatic drop of the penetration rate. It's also clear by that fact that subsequently the SPP and downhole pressure will increase.

2.5 Bit Balling

Bit balling is one of the drilling operational issues which can happen anytime while drilling. Bit balling is defined as the sticking of cuttings to the bit surface when drilling through Gumbo clay (i.e., sticky clay), water-reactive clay, and shale formations. During drilling through such formation, as the bit is rotating in the bottom hole, some of this clay get attached to the bit cones (Figure 1). If the bit cleaning is not proper, which happens usually due to poor hydraulics, more and more of this clay sticks to the bit. Finally, a stage is reached where all the cones are covered with this clay and further drilling is not possible. Bit balling can cause several problems such as reduction in rate of penetration (Rate of Penetration (ROP)), increase in torque, increase in stand pipe pressure (Stand Pipe Pressure (SPP)) if the nozzles are also stuck. Since drilling is not happening the volume of cuttings on the shale shaker are also reduced.

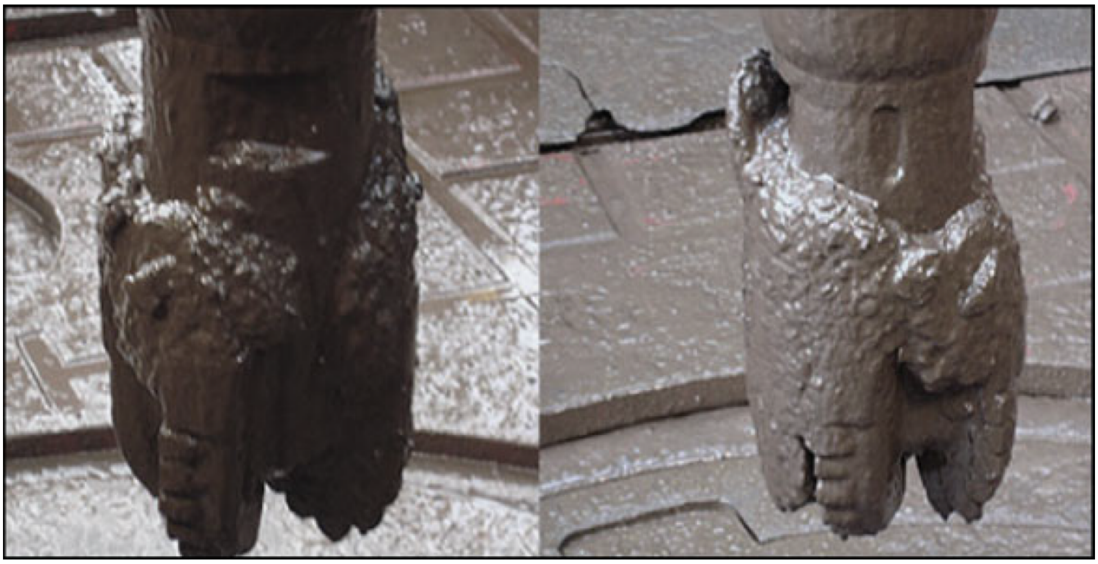

Figure 1: Drilling bit balled up

Personnel may eventually need to pull out of hole the bottomhole assembly (Bottomhole Assembly

(BHA)) to clear the balling issue at the bit.

There are many factors that affect the bit balling. These factors are: (i) formation – clay stone and shale has a tendency to ball up the bit even though one uses highly inhibitive water-based mud or oil-based mud; (ii) calcite content in clay – e.g., highly reactive clays with large cation exchange capacities; (iii) hydrostatic pressure in wellbore – high hydrostatic pressure (e.g., 5000 – 7000 Pounds per Square Inch (psi)) can induce bit balling issue in waterbased mud; (iv) weight on bit – high weight on bit will have more chance to create this issue; (v) bit design – poor bit cutting structure and poor junk slot area in Polycrystalline Diamond (PCD) bits contribute to this issue; (vi) poor projection of bit cutting structure due to inappropriate bit choice or bit wear; (vii) poor bit hydraulics – low flow rate will not be able to clean the cutting around the bit; (vii) poor open face volume (i.e., junk slot area) on Polycrystalline Diamond Compact (PDC) bits.

If there is a doubt that bit balling is going to be happening, it can be recognized by: (i) the ROP will decrease more than projection. For example, if crew drills 100 ft/hr and later the ROP drops to 50 ft/hr without any drilling parameters changed (e.g. less than expected in soft rock); (ii) drilling torque – drilling torque will be lower than normal drilling torque since most of the cutters are covered up by cuttings decrease in torque (i.e., less than expected and may show decrease with time); (iii) weight on bit – added weight on bit resulting in static or negative ROP reaction; (iv) standpipe pressure – standpipe pressure increases with no changes in flow rates or drilling parameters. Balling up around the bit reduce annular flowing area resulting in increasing pressure (e.g., 100–200 psi with a PDC bit with no associated increase in flow).

2.6 Formation Cave-in

The main cause of borehole caving (collapse) is simply the lack of suitable drilling mud. This often occurs in sandy soils where drillers are not using good bentonite or polymer. Now, the formation cave-in is defined as "pieces of rock that come from the wellbore; however, these pieces were not removed directly by the action of the drill bit". Cavings can be splinters, shards, chunks and various shapes of rock. These parts normally spall from shale sections and they become unstable (Figure 2.25). The shape of the caving can reveal the answer why the rock failure occurs. The term is typically used in the plural form. The main cause of borehole caving is lack of suitable drilling mud. This often occurs in sandy soil where drillers are not using good bentonite or polymer. The problems can be observed when fluid is circulating but cuttings are not being carried out of the hole. Borehole caving can also happen if the fluid level in the borehole drops significantly.

In such a situation, if the driller continues to push ahead and drill, the bit can become jammed. The hole will collapse when the casing team tries to insert the casing or the huge portion of the aquifer may wash out, making it very difficult to complete a good well. The solution is to get some bentonite or polymer or, if necessary, assess the suitability of natural clay for use as drilling fluid. Borehole caving can also happen if the fluid level in the borehole drops significantly. Therefore, it is necessary

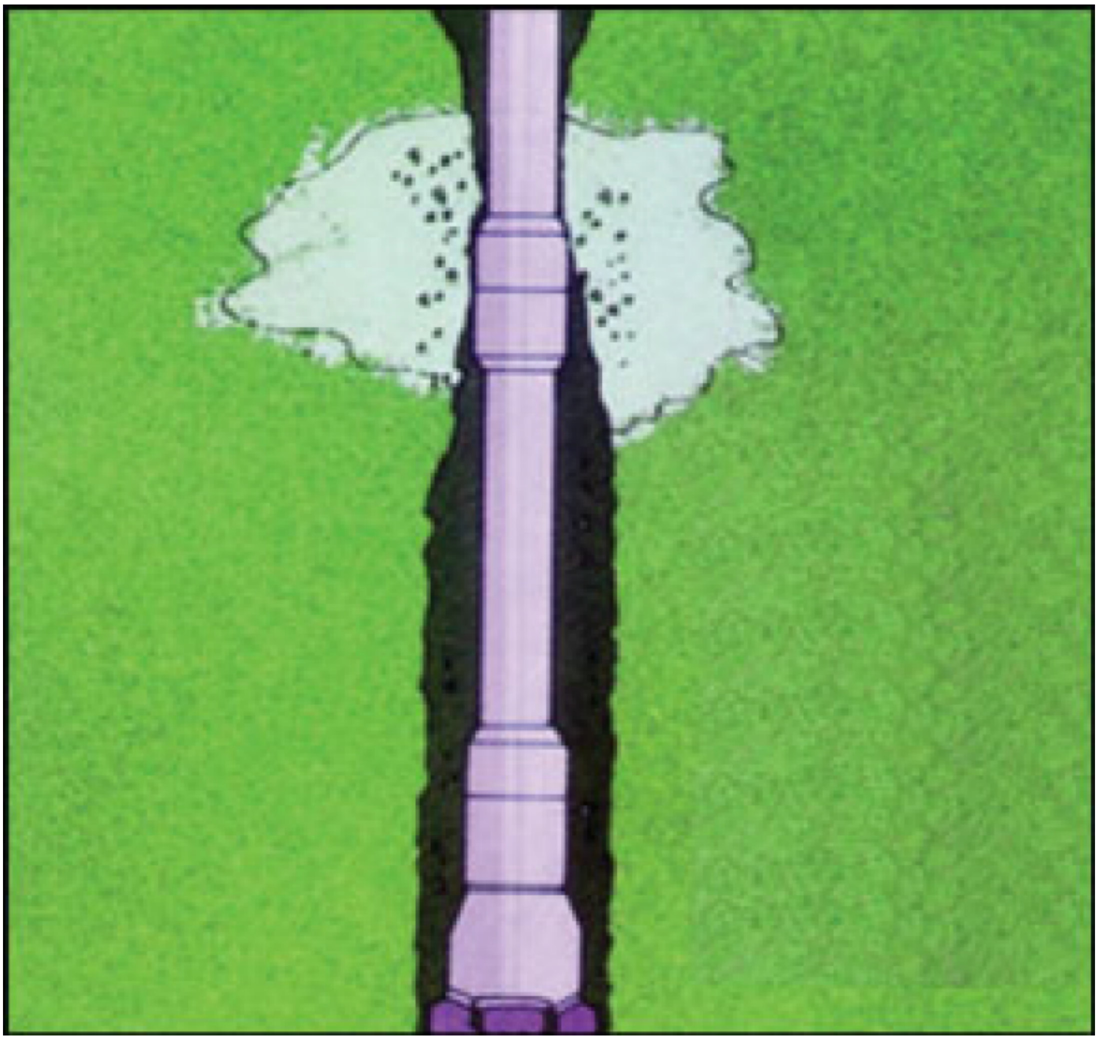

Figure 2: Formation cave-in

to have a loss of circulation or a night time stoppage, and thus slowly refill the borehole by circulating drilling fluid through the drillpipe. However, pouring fluid directly into the borehole may trigger caving. If caving occurs while drilling, check if cuttings are still exiting the well. If they are, stop drilling and circulate drilling fluid for a while. Sometimes part of the borehole caves while the casing is being installed, preventing it from being inserted to the full depth of the borehole. When this appears, the casing must be pulled out and the well redrilled with heavier drilling fluid. When pulling the casing, no more than 12.19 m (40 ft) should be lifted into the air at any time. If the driller pulls the pipe more than the specified length, it will cause thin-walled PVC to bend and crack.

2.7 Drilling Fluid and its Problems

A correctly formulated and well-maintained drilling system can contribute to cost containment throughout the drilling operation by enhancing the rate of penetration (ROP), protecting the reservoir from unnecessary damage, minimizing the potential for loss of circulation, stabilizing the wellbore during static intervals, and helping the operator remain in compliance with environmental and safety regulations. Drilling fluids can be reused from well to well, thereby reducing waste volumes and costs incurred for building new mud. Although currently reusing doesn't diminish costs at any appreciable manner, as more operators practice this recycling, the economics of recycling will improve. In addition, the introduction of environment- friendly additives is amenable to recycling and minimization of environmental footprints. To the extent possible, the drilling-fluid system should help preserve the productive potential of the hydrocarbon-bearing zone(s). Minimizing fluid and solids invasion into the zones of interest is critical to achieving desired productivity rates. The drilling fluid also should comply with established health, safety, and environmental (Health, Safety, and Environmental (HSE)) requirements so that personnel are not endangered and environmentally sensitive areas are protected from contamination. Drilling-fluid companies work closely with oil-and-gas operating companies to attain these mutual goals.

Drilling fluid (also called drilling mud) is an essential part in the rotary drilling system. Most of the problems encountered during the drilling of a well are directly or indirectly related to the mud. To some extent, the successful completions of a hydrocarbon well and its cost depend on the properties of the drilling fluid. The cost of the drilling mud itself is not very high. However, the cost increases abruptly for the right choice, and to keep proper quantity and quality of fluid during the drilling operations. The correct selection, properties and quality of mud is directly related to some of the most common drilling problems such as rate of penetration, caving shale, stuck pipe and loss circulation, and others. In addition, the mud affects the formation integrity and subsequent production efficiency of the well. More importantly, some toxic materials are used to improve the specific quality of the drilling fluid that are a major concern to the environment. Among others, this addition of toxic materials contaminates the underground system as well as the surface of the earth. Economically, it also translates into long-term liability as stricter regulations are put in place with increasing awareness of environmental impacts of toxic chemicals.

Therefore, the selection of a suitable drilling fluid and routine control of its properties are the concern of the drilling operators. The drilling and production personnel do not need detailed knowledge of drilling fluids. However, they should understand the basic principles governing their behavior, and the relation of these principles to drilling and production performance. They should have a clear vision of the objectives of any mud program, which are: (i) allow the target depth to be reached, (ii) minimize well costs, and (iii) maximize production from the pay zone. In a mud program, factors needing to be considered are the location of well, expected lithology, equipment required, and mud properties. Hence this chapter refers to the author's textbook Fundamentals of Sustainable Drilling Engineering for details in the basic components of mud, its functions, different measuring techniques, mud design and calculations, the updated knowledge in the development of drilling fluid and future trend of the drilling fluid. It is important because acquiring this knowledge will lead to an understanding of the real causes, and solutions related to drilling-fluid system.

2.7.1 Lost Circulation:

During drilling of hydrocarbon wells, drilling fluids are circulated through the drill bit into the wellbore for removal of drill cuttings from the wellbore. The fluids also maintain a predetermined hydrostatic pressure to balance the formation pressure. The same drilling fluid is usually reconditioned and reused. When comparatively low-pressure subterranean zones are encountered during a drilling operation, the hydrostatic pressure is compromised because of leakage into the zones (Figure 3.1). This phenomenon is commonly known as "lost circulation." So, lost circulation is defined as the uncontrolled flow of mud into a "thief zone" and presents one of the major risks associated with drilling. However, different authorities and researchers defined the lost circulation in a diversified manner. According to oilfield glossary it is defined as "the collective term for substances added to drilling fluids when drilling fluids are being lost to the formations downhole". Howard (1951) defined it as follows: "loss of circulation is the uncontrolled flow of whole mud into a formation, sometimes referred to as a "'thief zone.'" It is also defined as "the reduced or total absence of fluid flow up the annulus when fluid is pumped through the drillstring (Schlumberger, 2010). The complete prevention of lost circulation is impossible. However, limiting circulation loss is possible if certain precautions are taken. Failure to control lost circulation can greatly increase the cost of drilling, as well as the risk of well loss. Moreover, lost circulation may lead to loss of well control, resulting in potential damage to the environment, fire and/or harm to personnel. The risk of drilling a well in areas known to contain potential zones of lost circulation is a key factor in planning to approve or cancel a drilling project. The successful management of lost circulation should include identification of potential "thief zones", optimization of drilling hydraulics, and remedial measures when lost circulation occurs.

The problem of lost circulation was apparent in the early history of the drilling industry and was magnified considerably when operators began drilling deeper and/or depleted formations. The industry spends millions of dollars a year to combat lost circulation and the detrimental effects it propagates, such as loss of rig time, stuck pipe, blowouts, and frequently, the abandonment of expensive wells. Moreover, lost circulation has even been cited as the cause for production loss and failure to secure production tests and samples. On the other hand, controlling lost circulation can lead to plugging of production zones, resulting in decreased productivity. The control and prevention of lost circulation of drilling fluids is a problem frequently encountered during the drilling of oil and gas wells. During the drilling of wells, fractures that are created or widened by drilling fluid pressure are suspected of being a frequent cause of lost circulation. Of course, natural fractures, fissures, and vugs can create lost circulation even during underbalance drilling, in which fluid pressure doesn't play a role in lost circulation.

There are four types of formation and/or zones that can cause loss of circulation: (i) cavernous or vugular formations, (ii) unconsolidated zones, (iii) high permeability zones, and (iv) naturally or artificially fractured formations. Circulation loss can take place when a comparatively high pressure zone (subterranean) is encountered, causing cross flows or underground blowouts. Whenever the loss of circulation crops up, it is noticed by the loss of mud, and the loss zones are classified according to

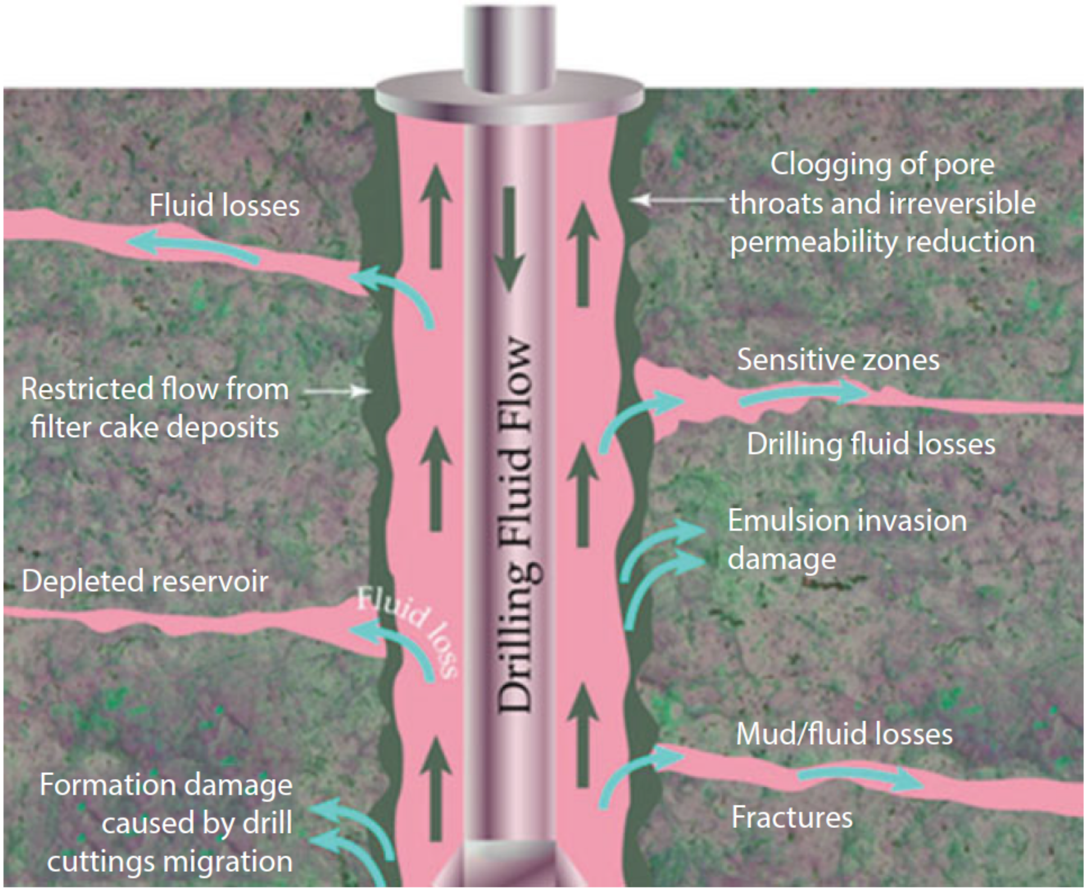

Figure 3: Lost-circulation zones

the severity of the loss: (i) “Seepage” with less than 10 /hour loss, (ii) “Partial Loss” for 10 to 500 bbl/hour loss, (iii) “Complete Loss” for greater than 500 bbl/hour loss. The lost circulation problem requires corrective steps by introducing lost circulation materials (Lost Circulation Materials (LCM)) into the wellbore to close the lost circulation zones. Many kinds of materials can be used as LCM. They include lowcost waste products from the food processing or chemical manufacturing industries. Figure 3.1 shows some examples of LCM as listed here.

Historically, mud losses have been dealt with by dumping some mica or nut hulls down a wellbore. There are numerous reports of ‘throwing in everything available’ to stop the extreme cases of mud loss. However, as the drilling operation becomes increasingly sophisticated and great feats are achieved in terms of drilling in difficult terrains and deep wells, simplistic solutions are no longer applicable. The industry is accelerating its activities in deepwater and depleted zones, both of which present narrow operating limits, young sedimentary formations, and high degree of depletion overbalanced drilling. These newfound prevailing conditions are susceptible to creating fractures and thus lead to lost circulation. Among others, drilling through and below salt formations presents a host of technical challenges as well. The thief zone at the base of the salt can introduce severe lost circulation and well control problems. This often results in loss of the interval or the entire well. The lost time treating severe subsalt losses can last for several weeks, with obvious cost implications, especially for deepwater drilling operations. Salt formations are common for oil-bearing formations that can be termed pre-salt if older or subsalt if younger. The oil-bearing formations of below salt in the Gulf of Mexico are mainly subsalt, whereas those in offshore Brazil are a mix of subsalt and pre-salt. The difficulty in managing a drilling operation through a salt formation lies in the fact the salt composition varies greatly. For instance, for the Gulf of Mexico, the salt formation contains mainly NaCl. On the other hand, the offshore Brazil salt formations have predominantly $MgCl_2$, which is far more reactive than NaCl. Salt formations are typical of other formations that are equally plastic and mobile can also be encountered during drilling. Controlling losses in this zone has proven to be extremely difficult as it involves matching the composition of the mud with that expected downhole, in order to minimize leaching of the in-situ salt into the drilling mud – a process that would create imbalance in the fluid system. Also, the plasticity of the salt may cause shifting. Therefore, the mud weight should be as close to overburden gradient, otherwise salt may shift into wellbore, leading to pipe being stuck. Very few lost circulation remedies have been successful, especially when using invert emulsion drilling fluids. Typically, a salt formation should be drilled with salt-tolerant water-based drilling fluids or with invert emulsion fluids. Deeper salt zones can be drilled with oil-based fluids that can be replaced with water-based mud after the salt formation has been passed. Such formations are available in the Bakken basin of the United States. In drilling through salt formations, considerations of density, salinity, and rheology are of paramount importance. The density consideration relates to maintaining bore stability. The salinity relates to preventing leaching from the salt formation as well as preventing intrusion and salt deposition in the wellbore. The rheology consideration relates to cleaning the salt cuttings and keeping them afloat during the return of the mud.

When dealing with induced fractures the problem is even more complicated because the shape and structure of induced formation fractures are always subject to the nature of the formation, drilling and mechanical effects, as well as geological influences over time. When the overbalance pressure exceeds the fracture pressure, a fracture may be induced and lost circulation may occur. By incorporating a lost circulation material (LCM) in the fracture to temporarily plug the fracture, the compressive tangential stress in the near-wellbore region of the subterranean formation increases, resulting in an increase in the fracture pressure, which in turn allows the mud weight to operate below the fracture pressure.

2.7.2 Mud Contamination:

Mud contamination is directly related to the drilling mud. In geotechnical engineering, drilling fluid is defined as a fluid used to drill boreholes into the earth. This fluid is used while drilling oil and gas wells and on exploration drilling rigs. Drilling fluids are also used for much simpler boreholes, such as water wells. There are three main categories of drilling fluids: (i) waterbased muds (which can be dispersed and non-dispersed), (ii) non-aqueous muds (which is usually called oil-based mud, and (iii) gaseous drillingfluid (in which a wide range of gases can be used). The primary functions of the drilling fluid are to (Hossain and Al-Majed, 2015): (i) remove and transport cuttings from bottom of the hole to the surface through annulus (i.e., clean the borehole from cuttings and removal of cuttings), (ii) exert sufficient hydrostatic pressures to reduce the probability of having a kick (i.e., control of formation pressure), (iii) cool and lubricate the rotating drillstring and drilling bit, (iv) transmit hydraulic horsepower to the bit, (v) form a thin, low permeable filter cake to seal and maintain the walls of the borehole and prevent formation damage (i.e., seal the thief zones), (vi) suspend drill cuttings in the event of rig shutdown so that the cuttings do not fall to the bottom of the hole and stick the drillpipe, (vii) support the wall of the borehole, and (viii) maintain wellbore stability (i.e., keep new borehole open until cased).

In addition to the above functions, there are some other secondary functions such as suspending the cuttings in the hole and dropping them in surface disposal areas, improving sample recovery, controlling formation pressures, minimizing drilling fluid losses into the formation, protecting the soil strata of interest (i.e., should not damage formation), facilitating the freedom of movement of the drillstring and casing, and reducing wear and corrosion of the drilling equipment, and provide logging medium. It is noted that the follwing side effects must be minimized to achieve the above functions (Hossain and Al-Majed, 2015): (i) damage to subsurface formation, especially those that may be productive, (ii) loss of circulation, (iii) wash and circulation pressure problems, (iv) reduction of penetration rate, (v) swelling of the sidewalls of the borehole creating tight spots and/or hole swelling shut, (vi) erosion of the borehole, (vii) attaching of the drillpipe against the walls of the hole, (viii) retention of undesirable solids in the drilling fluid, and (ix) wear on the pump parts.

Mud composition is affected by geographic location, well depth, and rock type. This contamination is altered as rock depth formulations and other conditions change. Drilling fluid maintenance costs can decrease greatly when proper solids control techniques are utilized. Adverse effects caused by drilled cuttings account for a major portion of drilling fluid maintenance expenditures. Drilling fluids are usually formulated to meet certain properties to enable the mud to carry out its basic functions. The importance of selection of a proper mud system which is free from contamination cannot be overemphasized. A poor design and contaminated drilling fluid can be very costly in the life of any well.

A contaminated mud is defined as “when a foreign material enters the mud system and causes undesirable changes in mud properties, such as density, viscosity, and filtration”. While drilling the drilling fluids is exposed to many contaminants, each one has different effects and consequences which lead to necessary treatment to minimize and avoid the drilling problems. Mud contamination can result from overtreatment of the mud system with additives or from minerals/material entering to the mud circulation system during drilling. Contaminated drilling fluids are a substantial potential hazard to the sensitive marine ecosystem. Therefore, there is a need for an appropriate process to treat the contaminated fluids sufficiently so that purified fluid, and thus unpolluted water can be discharged into the environment by the end of the process. Drilling fluids are the viscous emulsions which are circulated through the drilling pipe during drilling for crude oil to pump the milled product upwards at the same time as the oil. These emulsions rapidly become contaminated with mud, salt water, different minerals of the formation, and oil residues. As a result, drilling fluids should be continuously cleaned to ensure a smooth drilling process. The contaminated fluids become hazardous to the sea too.

2.7.3 Formation Damage:

Formation damage is an undesirable operational and economic problem that can occur during the various phases of oil and gas recovery. In general, formation damage refers to the impairment of the permeability of petroleum-bearing formations by various adverse processes (Figure 3.7). Formation damage can also be defined as the impairment of the unseen inevitable situation. It causes an unknown reduction in the unquantifiable permeability. Formation damage is defined as the impairment to reservoir (reduced production) caused by wellbore fluids used during drilling/ completion and workover operations. It is a zone of reduced permeability within the vicinity of the wellbore (skin) because of foreign-fluid invasion into the reservoir rock.

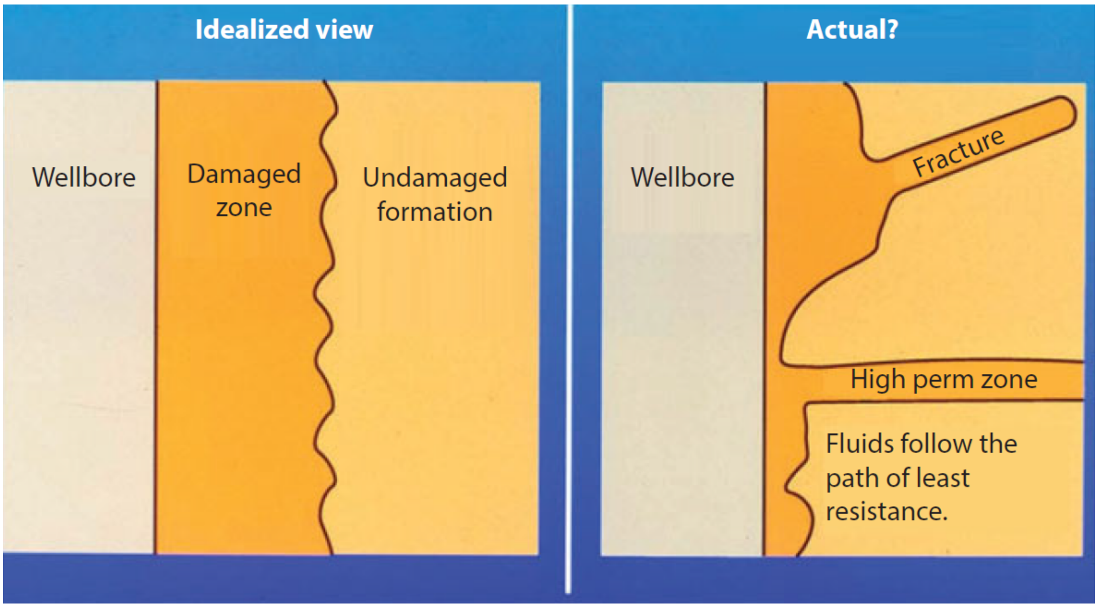

Figure 4: Formation damage

However, many researchers defined formation damage based on different contexts. According to Amaefule et al. (1988), “formation damage is an expensive headache to the oil and gas industry.” Bennion (1999) designated formation damage as, “the impairment of the invisible, by the inevitable and uncontrollable, resulting in an indeterminate reduction of the unquantifiable!” As stated by Porter (1989), “formation damage is not necessarily reversible” and “what gets into porous media does not necessarily come out.” Porter (1989) called this phenomenon “the reverse funnel effect.” Therefore, it is better to avoid formation damage than to try to restore it. Formation damage is an undesirable operational and economic problem that can occur during the various phases of oil and gas recovery from subsurface reservoirs including drilling, completion, stimulation, production, hydraulic fracturing, and workover operations (Civan, 2005). Formation damage indicators are (i) permeability impairment, (ii) skin damage, and (iii) decrease of well performance.

There are many factors which affect the formation damage. These factors are: (i) physico-chemical, (ii) chemical, (iii) biological, (iv) hydrodynamic, (v) thermal interactions of porous formation, particles, and fluids, and (vi) the mechanical deformation of formation under stress and fluid shear. These processes are triggered during the drilling, production, workover, and hydraulic fracturing operations.

As drilling fluid is one of the most important items that significantly influence the formation damage, several factors are considered for minimizing the formation damage while selecting a drilling fluid: (i) fluid compatibility with the producing reservoir, (ii) presence of hydratable or swelling formation clays, (iii) fractured formations, and (iv) the possible reduction of permeability by invasion of nonacid soluble materials into the formation.

The consequences of formation damage are the reduction of the oil and gas productivity of reservoirs and non-economic operation. These are: (i) reduction of reservoir, (ii) productivity, (iii) non-economic operations. Formation damage studies are important for: (i) understanding of these processes via laboratory and field testing, (ii) development of mathematical models via the description of fundamental mechanisms and processes, (iii) optimization for prevention and/or reduction of the damage potential of the reservoir formation, and (iv) development of formation damage control strategies and remediation methods. These tasks can be accomplished by means of a model-assisted data analysis, case studies, and extrapolation and scaling to conditions beyond the limited test conditions. The formulation of the general-purpose formation damage model describes the relevant phenomena on the macroscopic scale; i.e., by representative elementary porous media averaging (Civan, 2002).

Amaefule et al. (1988) demonstrated the formation damage mechanisms in four groups: (i) type, morphology, and location of resident minerals; (ii) in-situ and extraneous fluids composition; (iii) in-situ temperature and stress conditions and properties of porous formation; and (iv) well development and reservoir exploitation practices. They also classified the various factors affecting formation damage as: (i) invasion of foreign fluids, such as water and chemicals used for improved recovery, drilling mud invasion, and workover fluids; (ii) invasion of foreign particles and mobilization of indigenous particles, such as sand, mud fines, bacteria, and debris; (iii) operation conditions such as well flow rates and wellbore pressures and temperatures; and (iv) properties of the formation fluids and porous matrix. Figure 3.8 outlines the common formation damage mechanisms based significance. The specific mechanisms are shown in Figure 3.9. They greatly affect the formation damage, which are listed as: (i) clay-particle swelling or dispersion, (ii) wettability reversal, (iii) aqueous-filtrate blockage, (iv) emulsion blockage, (v) asphaltene and sludge deposition, (vi) scale and inorganic precipitation (i.e., mutual precipitation of soluble salts in wellbore-fluid filtrate and formation water), (vii) fines migration, (viii) particulate plugging (i.e., solids), (ix) bacteria, (x) saturation changes, (ix) condensate banking and (x) suspended particles.

2.7.4 Poor Hole Cleaning:

Annular hole cleaning, which defined as “the ability of a drilling fluid to transport and suspend drilled cuttings” is one of the most important mechanisms for cutting transport in rotary drilling. However, proper bottomhole cleaning is very difficult to achieve in practice. The jetting action of the mud crossing through the bit nozzles should provide sufficient velocity and cross flow across the rock face to effectively remove cuttings from around the bit as rock is newly penetrated. This would prevent cuttings from building up around the bit and teeth (i.e., bit balling), prevent excessive grinding of the

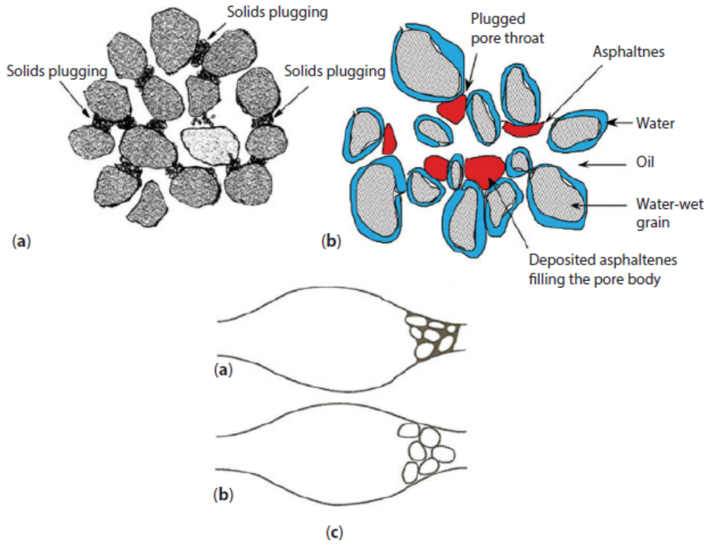

Figure 5: Formation damage caused by (a) solids plugging, (b) in situ asphaltene deposition, and (c) pore throat plug

cuttings and clear them on their way up the annulus, and maximize the drilling efficiency.

There are many factors that affect a part in the efficiency of bottomhole cleaning. These variables include: (i) bit weight, (ii) bit type, (iii) flow rate, (iv) jet velocity, (v) annular fluid velocity, (vi) nozzle size, (vii) location and distance from rock face, (viii) solids volume, (viii) hole inclination angle, (ix) cutting characteristics, (x) rate of penetration (ROP), (xi) drilling fluid properties, (xii) characteristics of the cuttings, (xiii) drillstring rotational speed, (xiv) differential pressure, and (xv) annulus or pipe eccentricity, etc. Proper bottomhole cleaning will eliminate excessive regrinding of drilled solids, and will result in improved penetration rates. The efficiency of hole cleaning can be achieved through proper selection of bit nozzle sizes. The maximum hydraulic horsepower and the maximum impact force are the two requirements to get the best hydraulic cleaning at the bit. Both these items increase when the circulation rate increases. However, when the circulation rate increases, so does the frictional pressure drop.

Inadequate hole cleaning can lead to costly drilling problems, such as: (i) mechanical pipe sticking, (ii) premature bit wear, (iii) slow drilling, (iv) formation damage (e.g., fracturing), (v) excessive torque and drag on drillstring, (vi) difficulties in logging and cementing, and (vii) difficulties in casings landing. The most prevalent problem is excessive torque and drag, which often leads to the inability of reaching the target in high-angle/extended-reach drilling.

2.7.5 Drilling Fluid Backflow:

Any back flow relates to pressure differences between the zones. Any time the pressure at a higher depth rises above the average pressure prevailing above in the drillpipe, backflow occurs. During a drilling operation, backflow is manifested through mud flow once the swivel is disconnected. It is caused by the pressurization caused by falling formation particles that end up pushing the drilling fluid up toward the Derrick. The backflow is an indication that the wellbore has not been cleaned and the cuttings not been removed adequately. During such backflow, the drillpipe should be reconnected immediately and mud should be circulated to clean up the wellbore. In case caving of the wellbore is suspected, the mud viscosity should be raised in order to restore the stability of the wellbore.

2.8 Borehole Instability

Wellbore stability is defined as "the prevention of brittle failure or plastic deformation of the rock surrounding of the wellbore due to mechanical stress or chemical imbalance". It is also called borehole stability, wellbore stability, and hole stability. So, borehole instability is the undesirable condition of an open hole interval that does not maintain its gauge size and shape and/or its structural integrity. Wellbore instability occurs because: (i) the creation of a circular hole into an otherwise stable formation, (ii) the hole tends to collapse or fracture unless supported, (iii) some rocks are very strong and will support themselves better than weaker rocks. Borehole instability appears as (i) hole pack off, (ii) excessive reaming, (iii) overpull, and (iv) torque and drag. This type of problems lead to the need for extra time to continue to drill, and development cost increases significantly.

Wellbore stability is affected by properties of the drilling mud and its interaction with the formation, by the mechanical properties of the formation and by the magnitude and distribution of the forces around the wellbore (Zeynali, 2012; Cheng et al., 2011). Any change in the mud system as well as the formation will affect the wellbore stability. This is unavoidable because the system is highly transient. In the presence of shales, sloughing or swelling shales can occur. Also, shales under abnormal pressures are also vulnerable to wellbore instabilities (Akhtarmanesh et al., 2013).

The main mechanisms of the shale instabilities i.e., the pore pressure transmission and chemical osmosis, were investigated by Akhtarmanesh et al. (2013) in order to evaluate their significance in the wellbore stability with respect to the physical and chemical properties of the shale and thermodynamics condition.

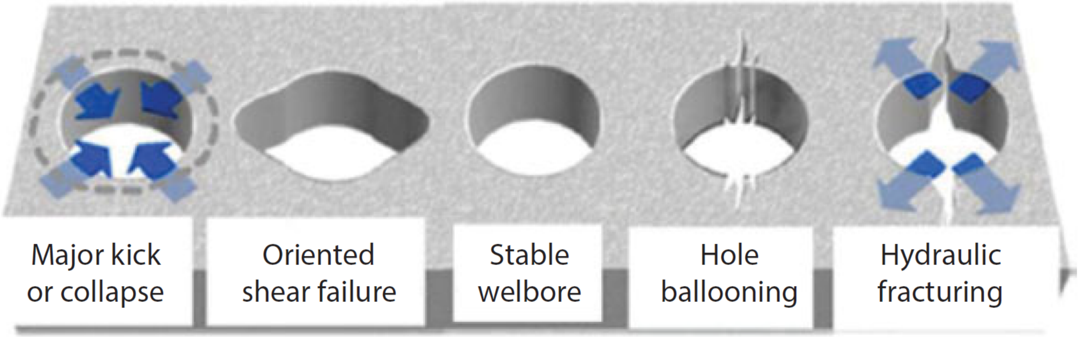

Figure 6: Schematic showing borehole failures in relation to the mud pressure (Zhang, 2013)

It was revealed that the shale formations can cause many problems such as partial or huge slump, which in turn results in pipe sticking or poor hole conditioning, bit balling and bit floundering as well as low quality logging and drilling fluid contamination due to its mixing with dispersed active clay particles. Zhang (2013) calculated the borehole failures, wellbore sliding/shear failures in relation to the mud weight along borehole trajectories with various drilling orientations versus bedding planes (Figure 6). As can be seen from Figure 6, rock anisotropy will affect horizontal stresses. This fact was considered by Zhang (2013).

Borehole instabilities lead to two types of problems, namely, tight hole and stuck pipe incidents, which are potentially dangerous and caused by the hole collapse (rock mechanical failure), inappropriate hole cleaning, differential sticking, and deviation from ideal trajectory.

2.8.1 Hole Enlargement (Washout):

In certain cases of wellbore instability, hole enlargement can occur. It is also recognized as washout because the hole becomes undesirably larger than expected. In general, most boreholes enlarge over time. Therefore, it is called a time-dependent collapse phenomenon. Hole enlargement is indirectly connected to lateral vibrations. It should be known that drillstring vibrations could lead to irreparable damage to the borehole, when having sufficient lateral amplitude to hit the wall. Vibrations can lead to large fractured areas, resulting in rock blocks falling into the well. In severe cases vibrations can lead to instability problems.

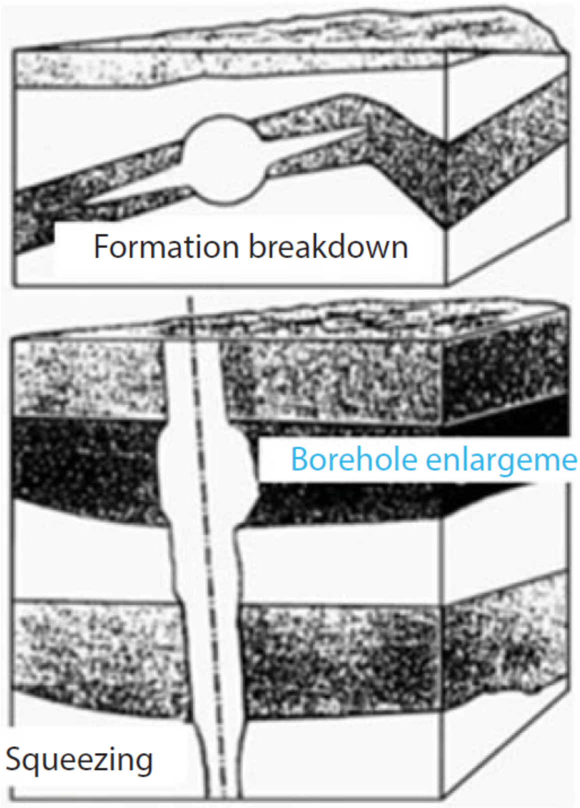

Figure 7: Types of borehole instabilities

When drilling through hard formations, the chemical interaction between the drilling fluid and the rock should be excluded as a cause of wellbore instability. When the drillstring hits the wellbore wall, enlargements will be created and the measurement while drilling (MWD) equipment may be destroyed. Vibrations are measured as accelerations, with sensors placed in a sub near the bit. Accelerations are measured in g´s, where 1g is the earth´s gravitational acceleration. The lateral accelerations can reach 80g´s in harsh environments and in severe cases 200 g´s has been recorded. In an operation experiencing 80g‘s, using a drill collar with 223 kg/m (150 lb/ft) of mass, the lateral force exerted by 0.3048 m (1ft) of drill collar will be 5.41 tons (11927lb). Five tons acting on the formation will naturally cause significant damage to the wellbore wall. When lateral vibrations are present, the drillstring will hit the wellbore wall repeatedly, impacting the wall multiple times. The number of times the drillstring hits the borehole, as well as the magnitude of the impact force will affect the wellbore stability and downhole conditions.

Hole enlargement introduces problems such as: (i) difficulties in removing rock fragments and drilled cuttings from the borehole, (ii) an increase in possible hole deviation, (iii) an increase in potential problems during logging operation, and (iv) reduced quality of the cement placement behind casing string. It is caused by hydraulic erosion, mechanical abrasion due to drillstring, and inherently sloughing shale.

2.8.2 Hole Closure (Creep):

It is also recognized as narrowing because the hole becomes undesirably narrower than expected. Occasionally it is referred to as a creep under the overburden pressure. Hole closure is a time-dependent phenomenon of borehole instability. At large, it appears in plastic-flowing shale, and salt sections. Hole closure introduces the problems such as: (i) an increase in torque and drag, (ii) an increase in potential pipe sticking, (iii) an increase in the difficulty of casing landing.

2.8.3 Fracturing:

While drilling, fracturing can take place if the wellbore mud pressure exceeds the formation-fracture pressure (Figure 8). Figure 8 (a) shows the general configuration of the fracture profile, whereas Figure 8(b) shows the casing settings within the general configuration. If the mud window is not properly maintained, the associated problems due to fracturing are possibility of kick occurrence, and loss circulation.

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2.8.4 Collapse and Burst:

Borehole collapse occurs when the drilling-fluid pressure is too low to maintain the structural integrity of the drilled hole. The associated problems are the pipe sticking, and possible loss of well.

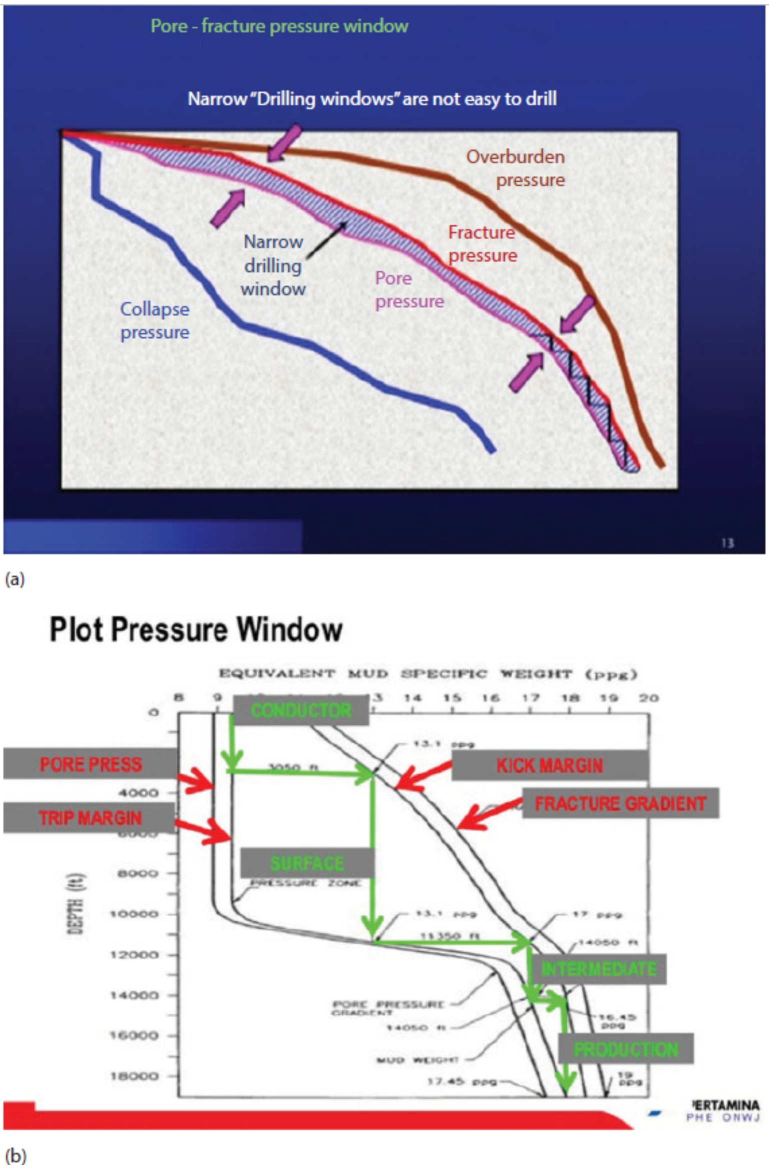

Figure 8: Drilling windows showing pore and fracture gradients

It is a shear type wellbore failure. This failure happens when the wellbore pressure is low. If the borehole pressure is low, the tangential stress becomes large enough for failure to occur. As a result, rock fragments fall off into the wellbore and thus form an elliptic borehole shape.

Pipe failure as a result of collapse or burst is rare; however, under extreme conditions of high mud weight and complete loss of circulation, pipe burst may occur. In order for a pipe to collapse, there has to be a weak point that acts as the trigger point. The following factors play a role.

Collapse pressure can be defined as an external pressure required causing yielding of drillpipe or casing. It can also be defined as the difference between external and internal pressure. The collapse pressure will occur if drillpipe is empty (i.e., no mud). It develops due to the difference in pressure inside and outside of drillpipe. In normal operation, the mud column inside and outside drillpipe are both equal in height and in density. Therefore, zero differential pressure across pipe body exists and thus no collapse happens. Normally, collapse pressure will happen during DST test.

2.9 Stuck Pipe

In extended reach drilling operations, a stuck pipe can lead to major nonproduction incidents (Aadnøy et al., 2003). Because of the delay involved as well as the possibility of losing the drillstring, pipe sticking can increase the drilling costs dramatically, leading to an increase of as much as 30%, particularly during offshore operations (Sharif, 1997).

A pipe is considered stuck if it cannot be freed from the hole without damaging the pipe, and without exceeding the drilling rig's maximum allowed hook load. Pipe sticking can be classified under two categories: differential pressure pipe sticking and mechanical pipe sticking (SPE, 2012). Mechanical sticking can be caused by junk in the hole, wellbore geometry anomalies, cement, key seats or a buildup of cuttings in the annulus (Bailey et al., 1991).

Stuck pipe incidents are one of the major operational challenges of the E&P industry and events usually lead to significant amount of lost time and associated costs (Isambourg, 1999). It costs the oil industry between $200 and $500 million each year, occurs in 15% of wells, and in many cases, is preventable (Figure 6.1). Stuck pipe remains a major headache that demands and is getting industry-wide attention (Bailey et al., 1991).

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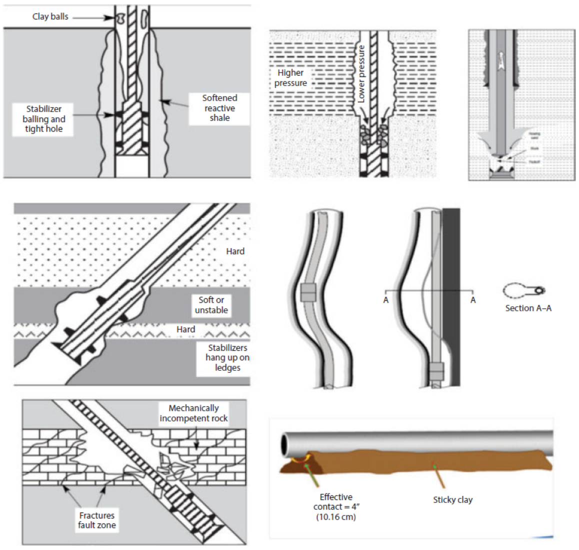


Figure 9: Different cases for stuck pipe

Stuckpipe problems often arise from non-optimal operation of the hydraulic system. Some of the indicators of differential-pressure-stuck pipe while drilling permeable zones or known depleted-pressure zones are an increase in torque and drag; an inability to reciprocate the drillstring and, in some cases, to rotate it; and uninterrupted drilling-fluid circulation.

2.9.1 Problems Related to Stuckpipe:

Stuckpipe problems often arise from non-optimal operation of the hydraulic system. Some of the indicators of differential-pressure-stuck pipe while drilling permeable zones or known depleted-pressure zones are an increase in torque and drag; an inability to reciprocate the drillstring and, in some cases, to rotate it; and uninterrupted drilling-fluid circulation.

2.9.2 Mechanical Pipe Sticking:

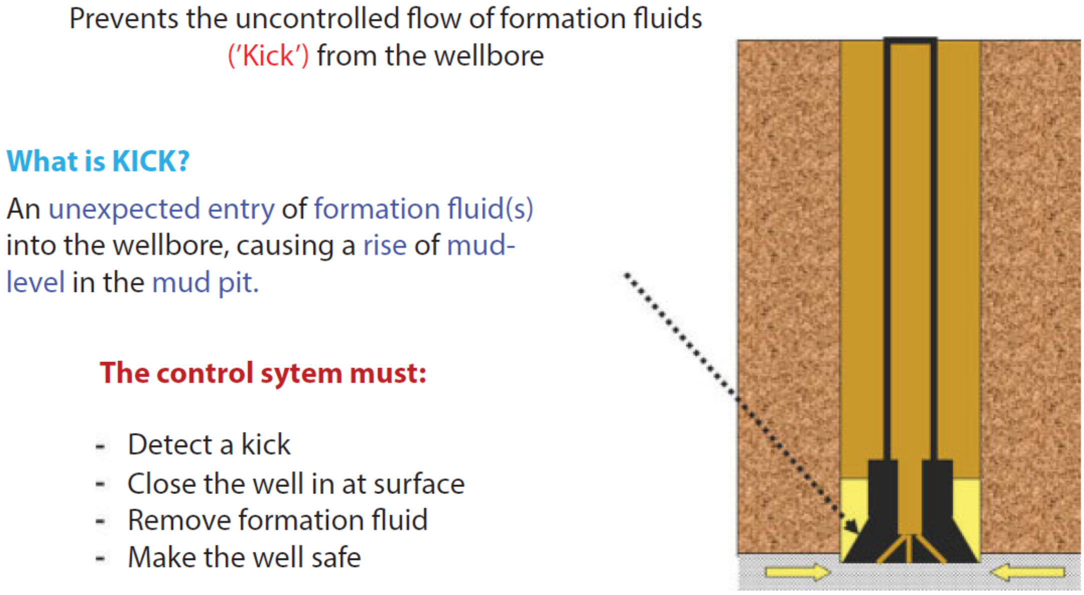
The causes of mechanical pipe sticking are inadequate removal of drilled cuttings from the annulus; borehole instabilities, such as hole caving, sloughing, or collapse; plastic shale or salt sections squeezing (creeping); and key seating. Excessive drilled-cuttings accumulation in the annular space caused by improper cleaning of the hole can cause mechanical pipe sticking, particularly in directional-well drilling.

The settling of a large amount of suspended cuttings to the bottom when the pump is shut down or the downward sliding of a stationary-formed cuttings bed on the low side of a directional well can pack a bottomhole assembly (BHA), causing pipe sticking. In directional-well drilling, a stationary cuttings bed may form on the low side of the borehole. If this condition exists while tripping out, it is very likely that pipe sticking will occur. This is why it is a common field practice to circulate bottom up several times with the drill bit off bottom to flush out any cuttings bed that may be present before making a trip. Increases in torque/drag and sometimes in circulating drillpipe pressure are indications of large accumulations of cuttings in the annulus and of potential pipe-sticking problems. Increases in torque/drag and sometimes in circulating drillpipe pressure are indications of large accumulations of cuttings in the annulus and of potential pipe-sticking problems.

2.10 Kicks

A kick is defined as an uncontrolled influx of formation fluid into the wellbore (Figure 10). If the formation pressure is higher than the mud hydrostatic pressure acting on the borehole or rock face, a kick may occur (Figure 11). When this type of situation arises, there is a great chance of formation fluids being forced into the wellbore. This unexpected formation fluid flow is called a kick. Kicks occur as a result of formation pressure being greater than mud hydrostatic pressure, which causes fluids to flow from the formation into the wellbore (Figure 10). In almost all drilling operations, the operator attempts to maintain a hydrostatic pressure greater than formation pressure and, thus, prevent kicks; however, on occasion the formation will exceed the mud pressure and a kick will occur. If this unwanted flow is effectively controlled, there would not be any kick (i.e., kick has been killed).

In contrast, if the flow is not controlled properly on time, the severity may result in “blowout.” Kicks



Prevents the uncontrolled flow of formation fluids
('Kick') from the wellbore

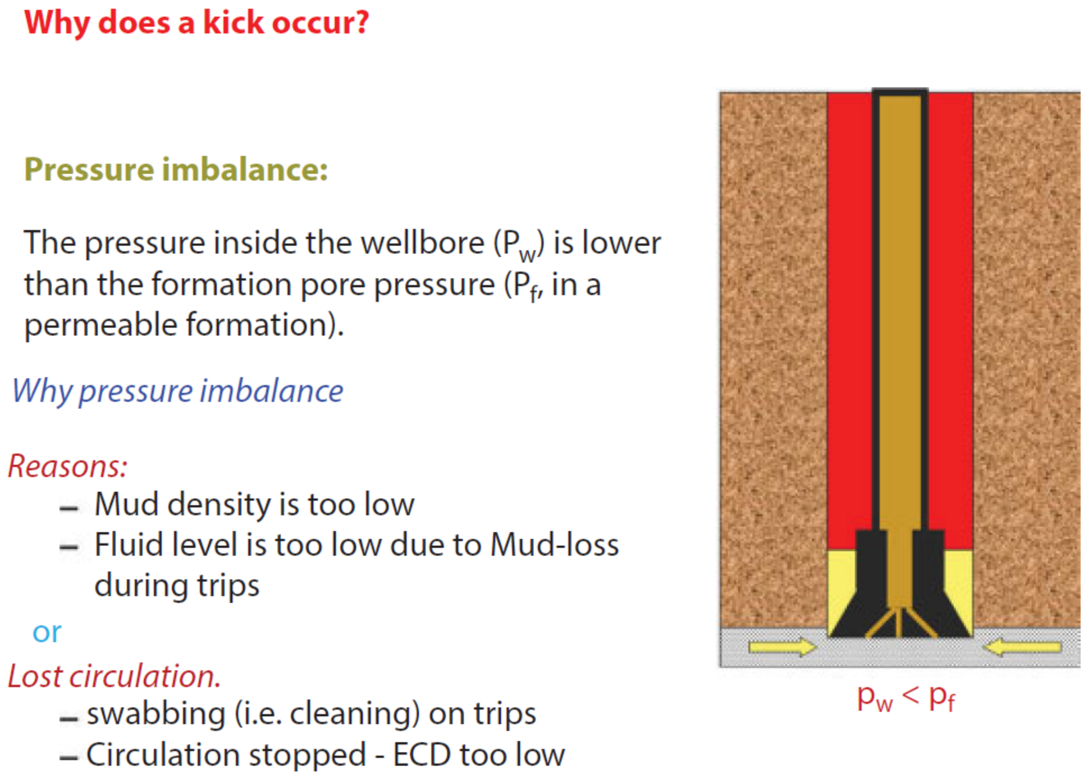
What is KICK?

An unexpected entry of formation fluid(s) into the wellbore, causing a rise of mud-level in the mud pit.

The control sytem must:

- Detect a kick
- Close the well in at surface
- Remove formation fluid
- Make the well safe

Figure 10: Schematic of formation fluid influx



Why does a kick occur?

Pressure imbalance:

The pressure inside the wellbore (P_w) is lower than the formation pore pressure (P_f, in a permeable formation).

Why pressure imbalance

Reasons:

- Mud density is too low
- Fluid level is too low due to Mud-loss during trips

or

Lost circulation.

- swabbing (i.e. cleaning) on trips
- Circulation stopped - ECD too low

$p_w < p_f$

Figure 11: Mechanism and reasons of kick

may happen because of the following reasons: (i) insufficient mud weight, (ii) improper hole fill-up during trips, (iii) swabbing, (iv) cut mud, (v) lost circulation, (vi) drilling into abnormal pressure, (vii) annular flow after cement job, (viii) loss of control during drill stem test (DST), (ix) drilling into adjacent wells, and (x) drilling through (i.e., shallow) gas zones at excessive rates.

Kick detection is mostly achieved by means of measurement and observation at the surface of the drilling fluid and drilling equipment. If a kick is not controlled, it will continue to grow in the wellbore until there is a blowout. Kick control is dependent upon time-to-detection. Kick detection in a subsea well is more problematic because the subsea well contains a large volume of drilling fluid between the wellbore and the surface kick detection – the volume of mud in the riser – which can mask a kick or delay detection. This additional volume in the riser may be up to twice as much as the volume in the wellbore. In any case, control of a kick in a subsea well can be improved if detection of the kick can be made sooner.

Early kick detection (Early Kick Detection (EKD)) is one of the most important focus areas for preventing loss of well control (Loss of Well Control (LWC)) events in the drilling operations. Bureau of safety and environmental enforcement (Bureau of Safety and Environmental Enforcement (BSEE)) defines the LWC as: (i) uncontrolled flow of formation or other fluids. The flow may be to an exposed formation (an underground blowout) or at the surface (a surface blowout, (ii) flow through a diverter, and (iii) uncontrolled flow resulting from a failure of surface equipment or procedures. If kicks are accurately detected and recognized earlier, they can easily be managed and thus stress levels on equipment and personnel can be reduced. This approach can lower down the risk of adverse consequences which ultimately helps in resuming safe and quick drilling operations. Two recent observations related to the importance of EKD are: (i) a study of the BSEE's incident database shows that approximately 50% of drilling related LWC events could have been prevented or improved with early kick detection, and (ii) not properly reading or interpreting kick indicators is a key factor. These results imply that an EKD system providing direct and unambiguous indications of a kick can alert the crew significantly earlier.

The severity factors of kicks are indicated by the Shut-in drillpipe pressure (SIDP) and the gain in pit volume. These factors are: (i) permeability (i.e., permeability of rock is the ability of the rock to allow fluid to move through it, (ii) porosity (i.e., porosity measures the amount of space in the rock containing fluids. So, for the above factor sandstone can be considered to have more of a kick than shale because sandstone has greater permeability and greater porosity), (iii) pressure differential (i.e., pressure differential is the difference between the formation fluid pressure and the mud hydrostatic pressure, (iv) amount of formation exposed to the wellbore, and (v) rate and the type of fluid flow into the wellbore before the well is shut-in (i.e., oil, gas, or water).

Controlling kick is the most important issue to safeguard the well and resume the drilling operations. The first step in controlling a kick is to detect it either: (i) very shortly after it occurs, or (ii) before a large volume of formation fluid has flowed into the wellbore. If the hole being drilled through formations has an increasing pressure gradient and in this case, the operator/driller should be alert for a pending kick. Schubert et al. (1998) demonstrated the operational procedures to close in the well. The kick control action items need to start as soon as the monitors/sensors indicate a kick. The kick is controlled by: (i) closing in the well, (ii) lighter kick fluids must be circulated out of the hole and replaced the heavier mud, and (iii) the driller immediately shuts off the rotary and starts to pick up the pipe, in case of drilling break.

Even though the signs may not be necessarily always positively identified as a kick, they provide a warning and should be monitored carefully. Sometimes the driller observes several indicators at the surface which might be due to events other than an influx. As a result, the signs are not always the final ones. For example, if the drill bit enters in an overpressured zone of a formation, the rate of penetration will increase. It might have happened due to the new formation encountered by the bit. On the other hand, some indicators need to be monitored continuously to restrict having kick. Normally there are two types of indicators: (i) primary indicators, and (ii) secondary indicators.

Primary Indicators: While drilling, there are some indicators that are more obvious than others and are therefore called primary indicators. The following are the primary indicators: (i) flow rate increase, (ii) pit volume increase, (iii) flowing well with pump shut off, and (iv) improper hole fill-up during trips.

Secondary Indicators: While drilling, there are some indicators that are not conclusive and may be due to some other reasons. The followings are the secondary indicators: (i) changes in pump pressure, (ii) drilling break, (iii) gas, oil, or water-cut mud, and (iv) reduction in drillpipe weight.

2.11 Drillpipe Failures

One of the drilling problems occuring during drilling is drillpipe failure. Drillpipe generally experiences torsion failure, although it can be pulled in two, particularly during heavy jarring. Inside the pipe, the innermost layer of drilling fluid is stationary and provides an optimum environment for the formation of corrosion pits that mature into holes in the pipe. When a hole in the pipe is found within two or three feet of the box or pin, it is almost a sure sign of internal corrosion failure. To complete the picture, it is better to review the types of detectable defects in drillpipe which seem to cause most of the trouble in service, which can be one of the following: (i) twist-off (excessive torque), (ii) parting (excessive tension), (iii) burst (excessive internal pressure) or collapse (external pressure), and (iv) fatigue (mechanical cyclic loads with or without corrosion).

Stuck pipe is caused by failure to clean the hole, by keyseats, and by differential (wall) sticking. Proper mud and proper hydraulics will keep the hole clean. Keyseats may be alleviated by the use of a keyseat wiper at the top of the bottomhole assembly. Overbalance is the cause of differential sticking; running a balanced mud system will address this problem.

Logging and wireline tools may become stuck in the hole at any time. Splitted wireline is very difficult to fish, as it has a natural tendency to ball up. Only relatively short sections can be recovered per fishing run. For this reason, all rope sockets should be crippled. This means that the weakest spot in the wireline needs to be at the point of attachment to the tool, so that the line may be pulled free of a stuck tool and recovered by its winch. Wireline tools should be fitted with a fishing neck so that they may be recovered with a normal fishing assembly. A sonde containing a radioactive source, an unusually expensive tool, or a tool lost in a washout or largediameter hole should not be treated in this manner. The wireline should be left attached to the tool and recovery attempted by the cut-and-thread procedure. Although this method is more complex and takes much longer, it is more likely to recover the fish.

One of the drilling problems occuring during drilling is drillpipe failure (Figure 12). To complete the picture, it is better to review the types of detectable defects in drillpipe which seem to cause most of the trouble in service, which can be one of the following: (i) twist-off (excessive torque), (ii) parting (excessive tension), (iii) burst (excessive internal pressure) or collapse (external pressure), and (iv) fatigue (mechanical cyclic loads with or without corrosion).

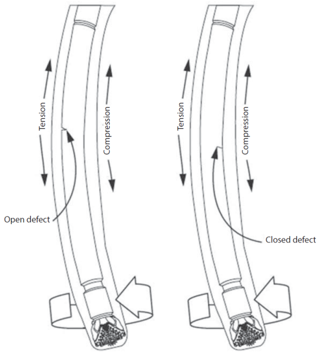


Figure 12: Drilling failure

Microcrack growth rates are also influenced by liquids present in the fluids, in the form of water, drilling mud or any other material. When the drill pipe rotates in a curved section of the wellbore, the microcrack constantly opens and closes passing through the short and long radius curvature. When the microcrack opens, the vacuum in it draws the liquid from the fluid on the same principle as a pump. Half-way through the cycle the microcrack closes and the liquid is trapped inside under pressure inducing further damaging effects.

Drillpipes are subjected to a variety of loads and environmental conditions. The drillpipe undergoes tensile stress (hook load) due to hanging weight of the string and BHA. Drillpipe section at any position in the string must have a strength, which is capable to withstand the tensile stress at that section in presence of other loads: radial pressure from drilling fluid, torsional stress from rotary torque and bending stress from doglegged holes. Pipe sections at the dogleg level are usually subjected to fatigue failure due to repeated bending stress and axial tension. In order to ensure a safe drillstring, the effective stress due to combined loads for a given drilling event is calculated at this level to check that the effective stress is below the strength of the pipe selected for the level. One widely used method for such assessment is given by von Mises. According to this method, the effective stress for combined loads is called von Mises stress and is kept below the yield strength of materials.

2.11.1 Tension Load:

Every drillpipe comes with a given tensile strength. The tension loading can be calculated from the known weights of the drill collars and drillpipe below the point of interest. The effect of buoyancy on the drillstring weight, and therefore the tension, must also be considered. Buoyancy forces are exerted on exposed horizontal surfaces and may act upwards or downwards. These exposed surfaces occur where there is a change in cross-sectional area between different sections (Figure 13). The load calculation can be started at the bottom of the drillstring and working up to the top. The tension loading can be determined for each depth. This is represented graphically by the tension loading line (Figure 13).

If the drillpipe is to remain in tension throughout the drilling process, drill collars need to be added to the bottom of the drillstring. The buoyant weight of the drill collars must exceed the buoyant force on the drillpipe. In addition, the neutral point shown in Figure 13 must be within the length of the drill collars. Drill collars are required to maintain the drillstring in tension because the function of the drill collars is to provide Weight on Bit (WOB). When selecting the drillpipe, the maximum tensile loads that the string could be subjected to need to be considered. In addition to the design load calculated on the basis of the string hanging freely in the wellbore, some other safety factors and margins are generally added: i) design factor – it is generally added to the loading line calculated above (in general, multiply by 1.3) which allows for extra loads due to rapid acceleration of the pipe, ii) margin of overpull (Margin of Overpull (MOP)) – it is generally added to the loading line because this allows for the extra forces applied to the drillstring when pulling on stuck pipe.

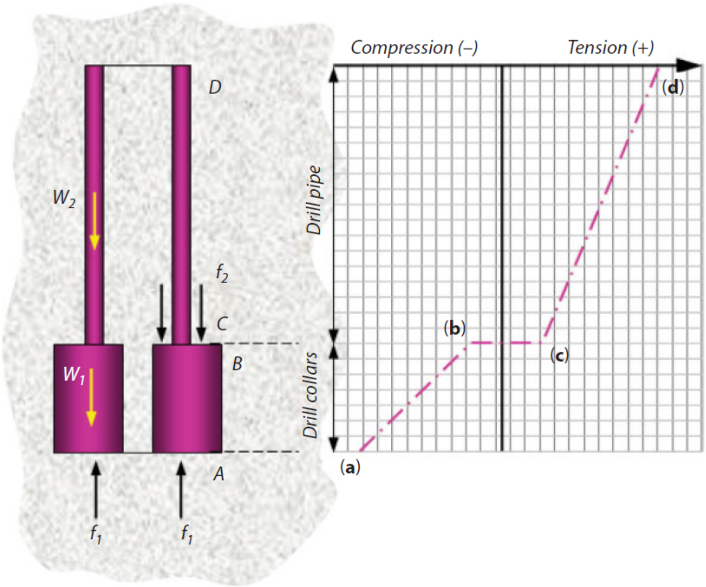


Figure 13: Axial Load distributions on the Drillstring

2.11.2 Fatigue:

Fatigue is the most common and costly type of failure in oil/gas drilling operations. Typically, fatigue is the result of sustained stress, often with periodic motion. Such sustained stress leads to development of microcracks. With continued increase and decrease of stress, these microcracks combine and form macrocracks that eventually reduce the strength of the concerned material. The combined action of cyclic stresses and corrosion can shorten the life expectancy of a drillpipe by thousandfolds.

2.12 Failures Caused by Downhole Friction Heating

The last few years have seen a dramatic increase in extreme friction heating induced failures of oilfield drillstring components. Although surface friction heating damage in the form of heat check cracking has been known to occur since the late 1940s, extreme friction heating failures due to the steel being heated above its critical temperature of 1,300–1,500 °F are now becoming more frequent.

Drillstring failures caused by friction heating of bottomhole assembly (BHA) components and drillpipe have increased dramatically over the last several years. Although drilling engineers are familiar with heat checking caused by downhole heating due to borehole friction, catastrophic overheating failures were rarely experienced prior to the last several years. The consequences of severe downhole heating can be dire often resulting axial separation of the drillstring creating potential well control safety issues, costly fishing jobs and other remedial efforts.

In one failure mode, the drillpipe is heated above a critical transformation temperature accompanied by a rapid decrease in tensile strength. Subsequently, the component fails under a tension loading, well below the rated strength of the drillstring. Recently, another failure mode of heavyweight drillpipe has been documented on three different wells where the pipe parted in a purely brittle mode.

These fractures occurred as a direct consequence of the steel being heated above its critical temperature, followed by rapid cooling (quenching) by the drilling fluids resulting in a very brittle, low toughness steel. The fracture surfaces that occur from this failure type often cause confusion during failure investigation due to the presence of flat fracture surfaces which are rarely seen in drillpipe and BHA components. Due to increasingly harsh drilling conditions it is likely these types of failures will become more common.

2.12.1 Heat Check Cracking:

Prior to the introduction of top drive drilling operations, heating damage to drillstring components was generally limited to heat checking of tool joint surfaces. Heat checking or heat check cracking is a friction heating phenomenon observable by the presence of multiple, fine shallow depth cracks that traverse in the direction perpendicular to the relative rotation direction of the contact surfaces. Figure 14 is an example of heat check cracking near the shoulder of a box tool joint. The large cracks are being formed from smaller cracks which bridged together. (Lucien Hehn et al., 2007). The direction of the cracks in Figure 14 is along the pipe axis direction and is perpendicular to the direction of rotation. The best method of detecting these fine cracks is wet magnetic fluorescent particle (wet mag) inspection; although magnetic powder is more easily available in the field it does not offer the high resolution afforded by wet mag which will detect virtually all small cracks of this type. Altermann et al., (1992) found that heat check cracks could be produced in the laboratory only when alternate heating and quenching of the friction heated contact surfaces occurred at every rotation cycle.

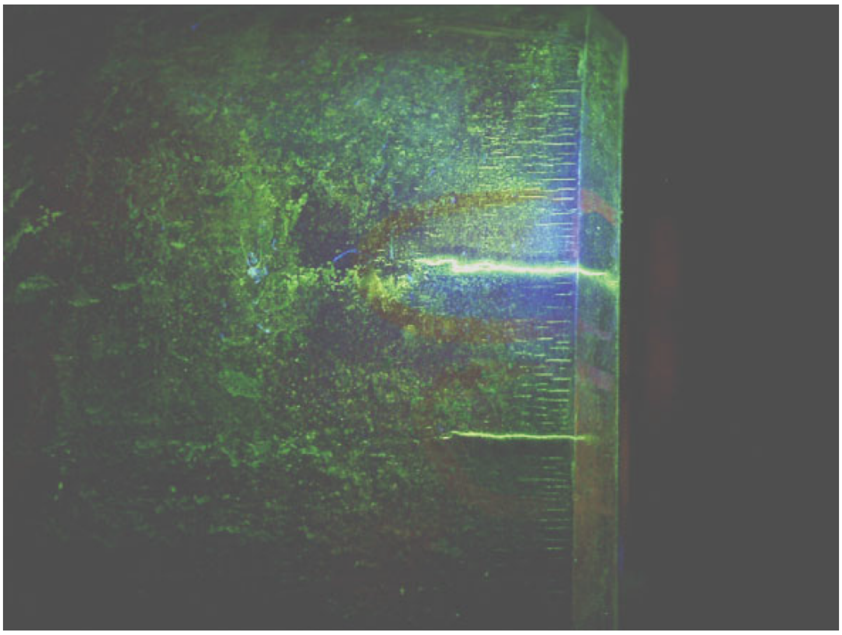


Figure 14: Example of heat check cracking near the primary shoulder of a box tool joint

This would imply that the driving mechanism for the generation of heat check cracking is heating to above the critical temperature followed by quenching in rapid cycles. Thus, heat check cracking has also been referred to as thermal fatigue.

Heat checking can occur anywhere on the drill stem surface but usually appears on the box tool joint. Although heat check cracks are usually limited from a few to several thousandths of an inch in depth, they can reach a depth of 0.25 in. or more. If a heat checked tool joint is repaired by turning down the OD, it should be reinspected afterwards since there is no way of knowing beforehand the depth of all the cracks. If joints containing these small shallow cracks are left in the string they can bridge together to form much larger cracks that can then grow to failure under assistance by stress corrosion cracking and corrosion fatigue.

2.12.2 Ductile and Brittle Fractures:

Metallurgical analysis of a failure is not possible in the field; however, there are general features of the fracture face that are indicative of brittle type failure. Brittle failure is caused by a conversion of the high toughness steel into a low toughness brittle form created by heating above temperature A. Properly manufactured drill stem products that have not been altered by downhole heating or other operating conditions will generally fail in ductile manner if overloaded, and this occurs at a predictable stress level. Ductile overload occurs from dislocation motion which can only be driven by shear stresses. The shear stress has a maximum at 45° to the direction of the applied stress (Figure 15a). Hence, the fracture face of a ductile overload failure always has surface features which take an orientation of 45° to the applied load.

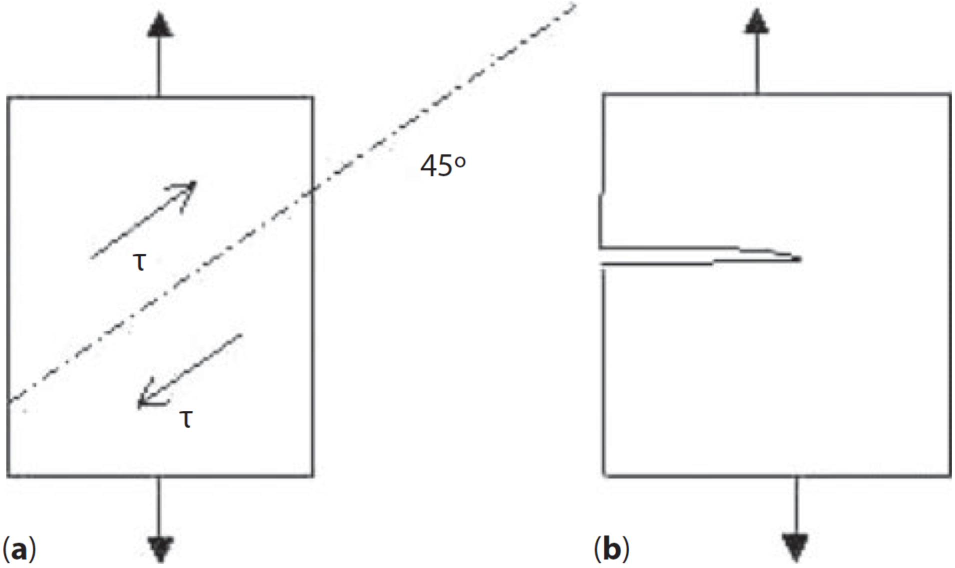


Figure 15: (a) Ductile fracture occurring at maximum shear stress, τ at 45º (b) Brittle fracture which requires crack propagation from stresses at 90º (Lucien Hehn et al., 2007)

In addition, ductile overload fracture faces show a fibrous texture from the shearing involved in the failure. In a brittle material, dislocations can move only with great difficulty, hence fracture occurs through the propagation and growth of a sharp crack. Sharp cracks are driven by loading in a direction 90° to the plane of the crack (Figure 15b). Hence, brittle fracture happens in a fundamentally different way than ductile overload. Any brittle type failure should be suspect as either a manufacturing error or a result of a downhole heating. When additional evidence of downhole heating such as friction wear and bluing of steel are also present, then the brittle fracture must be due to heating downhole and not a manufacturing process related defect.

The industry's continued advancement to drill deeper and further at increasing rotational speeds has led to an increasing trend of drill stem friction heating failures. One of the leading contributors to this increasing trend is the predominate use of top drives over kelly drive systems. Other contributing factors are the increasing frequency of directional drilling such as Extended Reach Drilling (ERD), the use of rotary steerable systems (Rotary Steerable Systems (RSS)) and the increasing total vertical depth (Total Vertical Depth (TVD)) of current wells. Friction heating failures involving unusual brittle fractures occur from the steel reaching either the A1 or A3 temperatures downhole. Characteristic features of these types of failures were given as well as methods to minimize their occurrence.

2.13 Vibration Induced Anomalies

Most petroleum wells experience shock and vibration. The degree of vibration is much higher in offshore applications. Because vibrations lead to fatigue, they are identified as one of the most significant factors that affect ROP and overall drilling efficiency. Fast drilling may instigate the generation of downhole vibrations, leading to premature failure of downhole components. In general, vibrations lead to wasted energy input. When vibrations are generated they will consume energy, and thereby prohibit efficient transfer of energy to the bit.

Vibrations are unavoidable since drilling is the destructive process of cutting rock either by chipping or by crushing. Because the drilling takes place within a massive solid rock system, it must involve vibrations. However, the degree of vibrations differs depending on the complexity of the terrain being drilled. Particularly intense vibrations take place in the poor drillability formations, deep well and ultra-deep well with the long drillstring, the deep water to ultra-deep water with vortex-induced vibration (Vortex-Induced Vibration (VIV)) of slender marine structures, coal and shale formation with borehole instability, irregular borehole diameter, and well trajectory increasing the level of drillstring vibration and shock (V&S). Drillstring V&S cause serious failures of drilling tools and while-drilling-monitoring equipment such as drillpipe, drill collar, logging while drilling (Logging While Drilling (LWD)), measuring while drilling (Measuring While Drilling (MWD)), pressure and temperature while drilling, engineering parameters while drilling (Engineering Parameters While Drilling (EPWD)), pressure while drilling (Pressure While Drilling (PWD)), and drill bits (Dong et al., 2016). Figure 16 shows typical drilling tools failure due to V&S in different drillstring components. Dong et al. (2016) reports that nonproductive time (Nonproductive Time (NPT)) caused by the drillstring V&S account for 25% of total NPT every year, which seriously restrict the development of automatic drilling and the ROP. This is illustrated in Figure 17.

Downhole vibrations can be catagorized into three primary classifications, axial, torsional and lateral/transverse. These three vibration modes have different vibrational patterns and each is generated by unique sources and leads to a unique set of problems. Combinations and interactions of these motions can exist, increasing the complexity of the vibration motions. It is also possible that some sort of synchronization may develop, leading to the onset of microfissures. Under sustained vibrations, catastrophic consequences can arise.

Figure 16: Damages caused by V&S in different drillstring components (Dong et al., 2016)

2.13.1 Axial Vibrations:

Axial vibrations are caused by the movement of the drillstring and may induce bit bounce. Bit bounce is seen when large weight on bit (WOB) fluctuations causes the bit to repeatedly lift off bottom, in vertical direction along the drillstring, and then drop and impact the formation (Aadnøy et al., 2009). Axial vibrations are detectable by the driller at shallow depths, as the vibrations travel to the surface through the drillstring. This mode of vibration is considered less aggressive than the other modes and the recorded axial accelerations are usually significantly lower.

It's because drilling process itself is self-correcting during the vertical segment of the well. However, the severity of axial vibrations is strongly affected by theinteraction between the bit and the formation. For instance, Tricone bits have a tendency of creating bit bounce, particularly in hard formations, and roller cone (Roller Cone (RC)) bits in general are believed to generate high axial vibration level. Tricone bits consist of three cones and are most often used when drilling the top sections. When the three cones move up and down together a three-lobe pattern is generated, thus forming chaotic patters on the bottom. The shape of the original pattern can be compared to a sinusoidal curve. This chaotic patterns emerge due to combination of various periodic signals. An overall axial vibration mode emerges when the cones interact with the underlying formation.

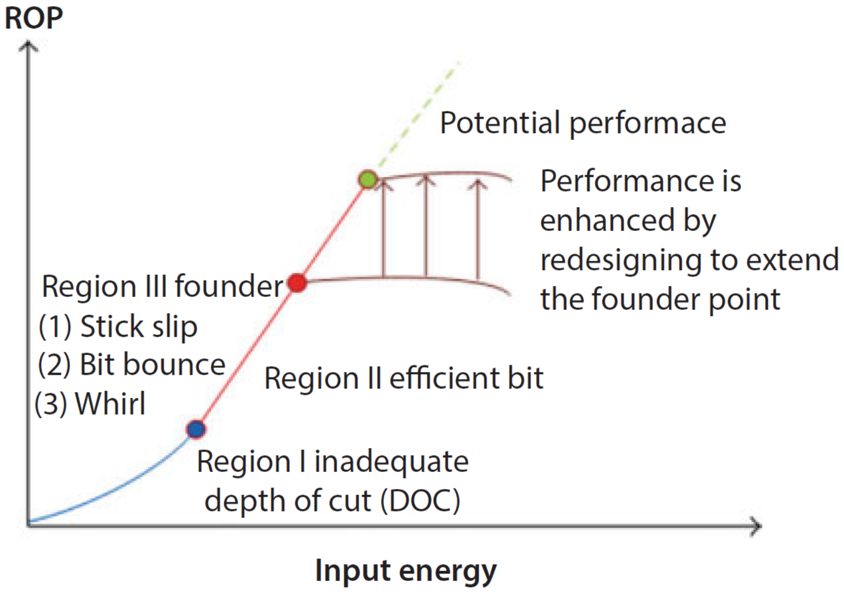


Figure 17: The relationship of drilling parameters, ROP, and input energy (Dong et al., 2016)

Real-time remedy of axial vibrations is to adjust the Rotations per Minute (RPM) and WOB, for instance, by increasing the WOB and reducing the RPM. This changes the drillstring energy. If this does not work, it is recommended to stop drilling to allow the vibrations to cease and thereafter start drilling with different parameters (Schlumberger, 2010). This must be done in correlation with the ROP, as WOB and RPM are the most highlighted parameters affecting the drilling speed. In extremely hard formations, it can be difficult to completely eradicate axial vibrations, as a minimum ROP is required and specified by the operator. A less aggressive bit should be considered as a possible last-ditch remedy.

2.13.2 Torsional Vibrations:

Torsional vibrations are twisting motions in the drillstring. These vibrations are mainly caused by stick-slip. The vibrations are generated when the bit and drillstring is periodically accelerated or decelerated, due to frictional torque on the bit and BHA. Torsional vibrations lead to irregular downhole rotations. Non-uniform rotation is developed when the bit becomes temporary stationary, causing the string to periodically torque up and then spin free. Every time such motion occurs, a permanent mark on the drillstring is made. The severity of stick-slip will affect how long the bit stays stationary and consequently the rotational acceleration speed when the bit breaks free. The downhole RPM can become several times larger than the RPM applied at surface. Torsional vibrations are highly damaging and are identified as one of the main causes of drillstring fatigue and bit wear. In severe cases, over-torqued connections and drillstring twist-offs have been observed. When this phenomenon occurs, it consumes part of the energy originally dedicated to the ROP and it has been documented that stick-slip can lead to the ROP being decreased by 30–40% (Aadnøy et al., 2009).

Stick-slip can either be caused by the rock-bit interaction or by the interaction between the drillstring and the borehole wall. The vibration mode is typically seen in environments such as high angle wells with long laterals and deep wells. Other factors, such as aggressive polycrystalline diamond compact (PDC) bits with high WOB, and hard formations or salt also seem to instigate the generation of stick-slip.

Torsional vibrations are damped by the torsional stiffness of the drillstring and by the friction against the wellbore wall. The stiffness in torsional direction is not as significant as the stiffness in the length direction and hence the dampening is less pronounced than for axial vibrations. Due to the elasticity of the drillstring, the rotations often become irregular. A stiffer drillstring could potentially dampen the stick-slip indices. The vibration mode is observed at surface as large variations in torque values. Even in deviated wells, torsional vibrations can be detected by surface measurements and reduced by the driller (Schlumberger, 2010).

The severity of torsional vibrations is dependent on both RPM and WOB, as for axial vibrations. The ideal RPM varies according to the conditions in the well. With higher WOB the possibility of stick-slip will increase, as the cutters will dig deeper into the formation and thereby increase the torque and lateral forces on the BHA. During drilling, the stick-slip level can be reduced by lowering the WOB and increasing the RPM.

As discussed in previous sections, a number of tools can be added to the BHA that would alleviate torsional vibration by acting as a detuner or vibration damper. The detuner effect changes the stiffness of the drillstring and hence the natural frequency, thus separating the excitation frequency from the component's natural frequency, whereas the damper effect absorbs the vibration within the drillstring, reducing the effects of the torsional vibration.

2.13.3 Lateral/transverse Vibrations:

Lateral vibrations are seen as side-to-side motion in transverse direction relative to the string, as shown in Figure 18.

This mode is best described as a whirling motion. This motion is limited to the scenarios for which enough lateral movement in the BHA to bend out and touch the borehole wall. In its severest form, lateral/transverse vibrations can trigger both axial and torsional vibrations, a phenomenon known

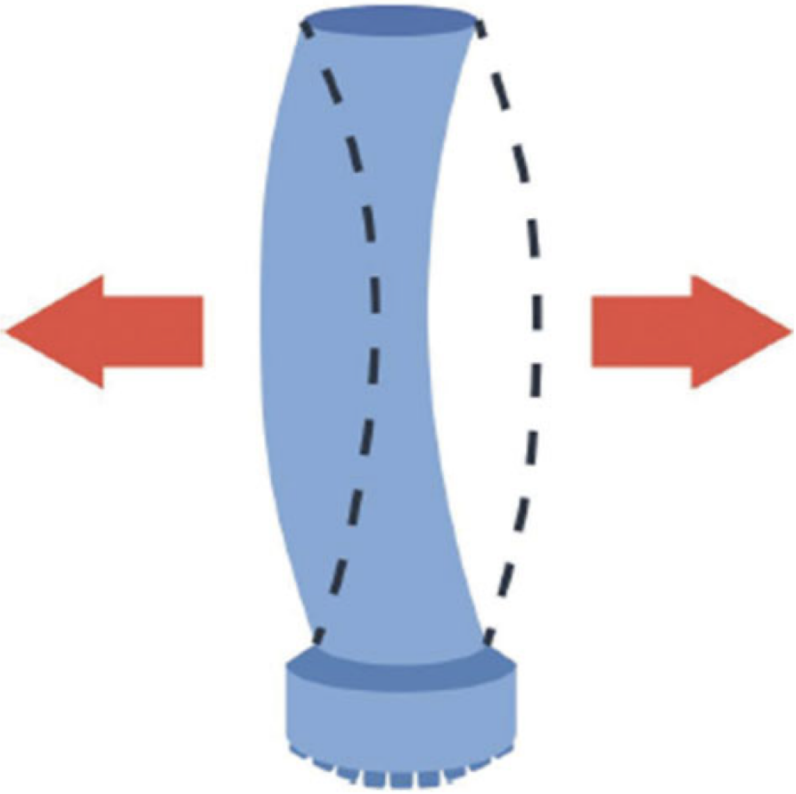


Figure 18: Lateral/transverse vibrations)

as mode coupling. This is the process that can create small-scale resonance from perturbations in different directions. As such, this is considered to be the most destructive mode in a drilling operation. Severe damage to the BHA can occur, leading to problems, such as, over gauge holes, damaged equipment, lack of well direction control and drillstring fatigue.

Lateral/transverse vibrations are not easily detected at the surface, as the vibrations tend to dampen out before its existence is ‘felt’ at the surface. As such, these vibrations are difficult to detect, thus eluding preventative measures.

The effects of lateral vibrations on bottomhole assembly (BHA) during back reaming operations were evaluated by Agostini and Nicoletti (2014). It was shown that the occurrence of abnormal lateral vibrations during back reaming can effectively cause BHA electronic equipment failure, falling rocks into the well, and drillstring blockage. This in turn can lead to drilling malfunctions. Other works also indicate that the stick–slip vibration on a drillstring length of 3000 m is detrimental to the drilling equipment and the drilling efficiency (Gulyaev et al., 2013).

In order to alleviate the problem of transverse vibrations, the RPM is often reduced, while the WOB is increased. If the vibrations continue, the assembly is picked off bottom, allowing the torque to unwind, and the drilling restarts with different drilling parameters. The energy imparted is also dependent on the free collar length and thus a shorter, stiffer BHA in lateral direction could be implemented to prevent sideways motion.

In the mid-1990s, a new line of anti-whirl drillbits were introduced (Sinor, 1995). Even though the original application of the technology involved coring, it has gained popularity for drilling in difficult-to-drill terrains (Dong et al., 2016).

2.14 Drillstring Failures

The first section of the drillstring is the BHA, including drill collar and drill bit, the two components that are used to crush the rock and create stability for proper directing of the hole. The second section is a heavyweight drillpipe (HWDP) used to provide a flexible transition between drill collars and the drillpipe. These HWDP reduce the fatigue failures that could occur above the BHA in addition to increasing the weight on the drill bit. The third section is the drillpipe that makes up the majority of the drillstring all the way up to the surface. Each drillpipe comprises a long tubular diameter portions with an outside diameter called the tool joints that serve as the connector between two pipes. The pipes are furnished with a male "pin" threaded connection at one end and a "female" housing connection. Such a trait makes the drillpipe flexible yet robust. Throughout the drillpipe, the tool joints have the same diameter, which is slightly higher than the drillpipe diameter. Even though the entire drillpipe has the same diameter, its upper section (closer to the surface) is handled by using a higher strength material for them to be able to support higher axis loading, which is clearly much greater than that of the lower portion. Great advances have been made in terms of drilling speed as well as accuracy. However, there remain several trouble spots that can lead to delay in drilling, thereby costing time and resources.

The cost of drilling a well is measured in tens of millions of dollars. The incidence of downhole failure of the drillstring can increase this figure dramatically. The focus placed on cost reduction in the early 1990s – when oil prices were much lower than today's levels – resulted in some scrutiny of drilling operations, amongst other areas. Drillstring failure was a natural part of this.

Failure of drillstring is a costly problem in the oil and gas industry. Many studies have addressed the issue, often in considerable detail, but the frequency of occurrence remains excessive. Torque, tension, compression, and bending stresses can be correctly predicted for a known or assumed hole geometry but deviation from this ideal of the actual borehole geometry leads to uncertainty and error in predictions of the stress-state.

Figure 19 shows drillstring and bottomhole assembly components where failures continue to afflict the oil and gas industry, annually involving direct and consequential costs extending to millions of dollars. This wide-ranging problem has been exacerbated by recent industry trends towards the drilling of deep, deviated wellbores. Further intensification of the problem may occur if extended reach, horizontal drilling and multiple lateral completion programs become more prevalent.

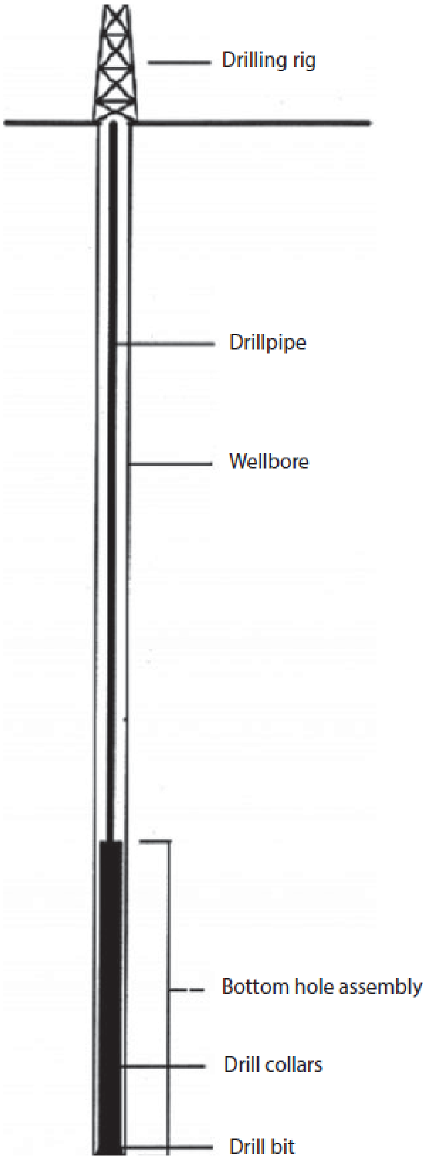


Figure 19: Drillstring (K.A Macdonald, 2007)

Drillstring failures, even such routine failures as drillpipe washouts, can contribute significantly to the cost to drill today's wells. These costs grow exponentially when the failure results in fishing operations, and in extreme cases, failures can even cause well-control problems. In 1985, McNalley reported that 45% of deep well drilling problems were related to drillstring failures. Moyer and Dale concluded that drillstring separations occurred in one in seven wells and cost an average of $106,000. For such routine failures as drillpipe washouts, the failure often is accepted as "part of the business". The offending components are replaced and operations are resumed. If the cause of failure is unusual, analysis must be performed, the results should be reported and recommendations are made to prevent similar failures. These failures seem to be handled case by case without an overall approach to prevention.

Drillstring failure is due to a lot of reasons, which may occur either individually or in-group. In order to prevent or at least minimize occurring drillstring failure, all reasons should be recognized. To do that, one should have a well-designed approach to testing all factors affecting drillstring failure, to eliminate the problem early. Early cases studied were analyzed without an overall approach and without revealing the actual reasons of the drillstring failure.

The range of commonly encountered primary damage mechanisms covers ductile fracture, brittle fracture, fatigue and stress corrosion cracking (Figure 20). Various simple and complex combinations can also occur. A consistent feature where twist-off has occurred is that postseparation damage to fracture surfaces can often be very severe, Figure 20, obliterating much of the detail of the fracture morphology required to aid identification of the failure mode. This is due to the failure remaining undetected at the surface and consequently both weight-on-bit and rotation continues.

(a) Top end (148-A) **(b)** Bottom end (148-X)

(c) Erosion at upper VBR **(d)** Erosion at middle VBR

Figure 20: Drillstring failure (nola.com)

In addition, the large pressure differential drives flow of the mud from pipe bore to annulus should a leak path become available, resulting in washout damage (Figures 21 and 22).

2.15 Drill Bit Jamming

While drilling long sections of an abrasive formation, the gauge protection on the bit and stabilizer can became so worn out that it becomes ineffective. The jamming generally occurs when a new bit is lowered down a hole, previously drilled with a worn out bit. The drillpipe and bit may become jammed when the drilling fluid is not allowed to thoroughly clean the borehole prior to stopping to add another joint of drilling pipe or the fluid is too thin to lift gravel from the bottom of the borehole. In that sense, a driller can anticipate the jamming problem by noting when the drill bit starts to catch while drilling.

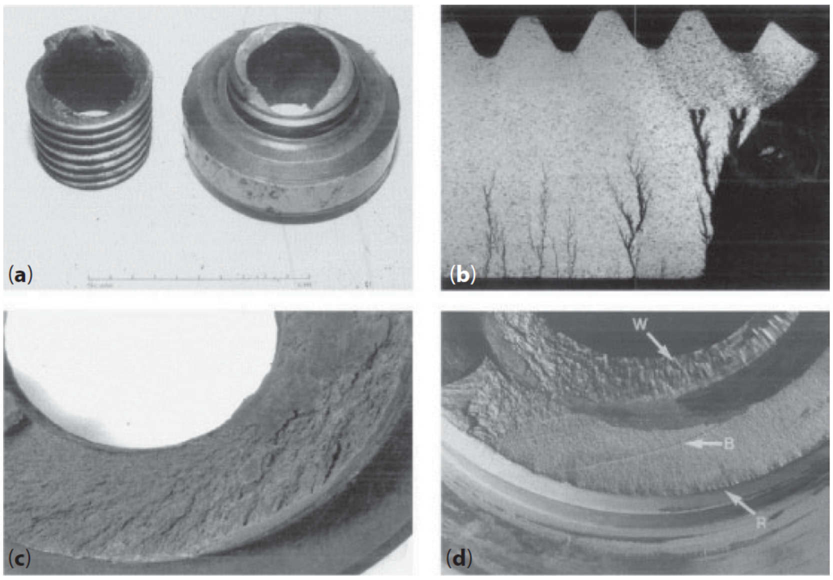


Figure 21: Commonly encountered modes of fracture: ductile (a); brittle (b); Stress Corrosion Cracking (SCC) (c) and fatigue (d) where R – radial steps along initiation region at thread root; B – beach marks from fatigue and W – washout. (Macdonald, 2007)

Figure 22: Post-separation damage to fracture surfaces of a BHA connection. (Macdonald 2007)

2.16 Twist-off

Twist-off is a parting of the drillstring caused by metal fatigue or washout (Figure 23). If the drillpipe twists off, this means that the pipe was twisted along its vertical axis. As a result, the fluid cycle will stop leading to expose the bit into heat (i.e., no cooling + no lubrication). Twist-off will also eliminate the nozzles fluid pressure which supports the drilling operation. It can lead to a drillpipe fatigue failure (Figure 24). This typically happens when lower sections of the pipe get stuck.

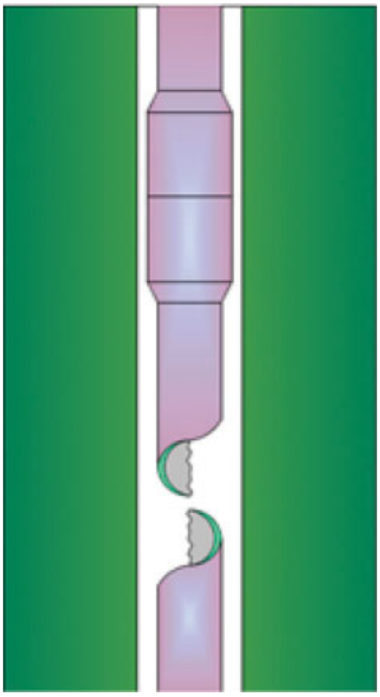


Figure 23: Pipe twist-off

Figure 24: Pipe failure due to twist-off and/or fatigue

There are early symptoms of twist-off such as the torque indication. The higher the torque deflection during drilling operation, the more it is likely to get twist-off. Therefore, the driller should be aware of the situation.

2.17 Drilling through naturally fractured or faulted formations

Borehole instability is significant in naturally fractured and/or faulted formations. A natural fracture system in the rock can often be found near faults, although the direction of principal axis of the Rose diagram is perpendicular to the direction of the fault (Islam, 2014). As the drilling operation continues, rock bodies near faults can be broken into large or small pieces. If they are loose they can fall into the wellbore and jam the string in the hole (Goud, 2017). Even if the pieces are bonded together, impacts from the BHA due to drill string vibrations can cause the formation to fall into the wellbore, thus creating stuckpipe problems. As Goud (2017) points out, this type of stuckpipe problems are common in drilling through faulted or highly fractured limestone formations. Often, this problem can be alleviated by choosing an alternative RPM or changing the BHA configuration to minimize high-level shocks.

Figure 25 shows possible problems because of drilling a naturally fractured or faulted system. As shown in this figure, whenever a fractured formation is traversed, the borehole wall is susceptible to shed debris that can enlarge the wellbore and at the same risk jamming the drill collar. This chain of problems become more severe if weak bedding planes intersect a wellbore at unfavorable angles. Such fractures in shales may provide a pathway for mud or fluid invasion that can lead to time-depended strength degradation, softening and ultimately to hole collapse. The relationship between hole size and the fracture spacing will be important in such formations.

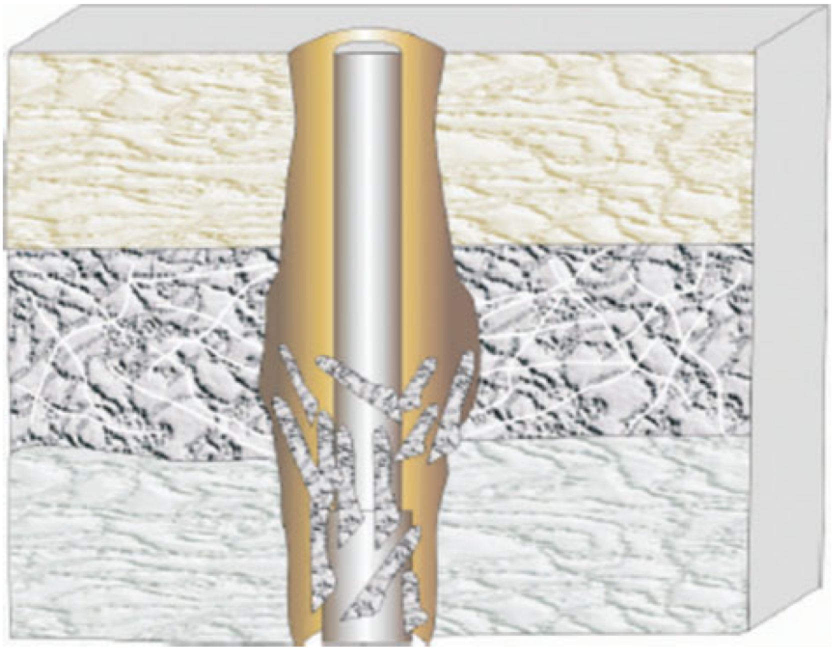


Figure 25: Drilling through naturally fractured or faulted formations (from Pašić et al., 2007)

2.18 Drilling through tectonically stressed formations

Wellbore instability can occur when formations, under high level of natural stress, are drilled and there is a significant difference between the near wellbore stress and the restraining pressure provided by the drilling fluid density. Tectonic stresses build up in areas where rock is being compressed or stretched due to movement of the earth's crust. Even though this is a very slow process, it is still a dynamic process and the rock in these areas is in a state of being buckled by the pressure of the moving tectonic plates. When a hole is drilled in an area of high tectonic stresses, the rock around the wellbore will collapse into the wellbore and produce splintery cavings similar to those produced by over-pressured shale (Figure 26). Connecting cavings to borehole instability and its mechanism entails correct description coupled with proper interpretation of the geology, geomechanics, and drilling system and process (Kumar et al., 2012).

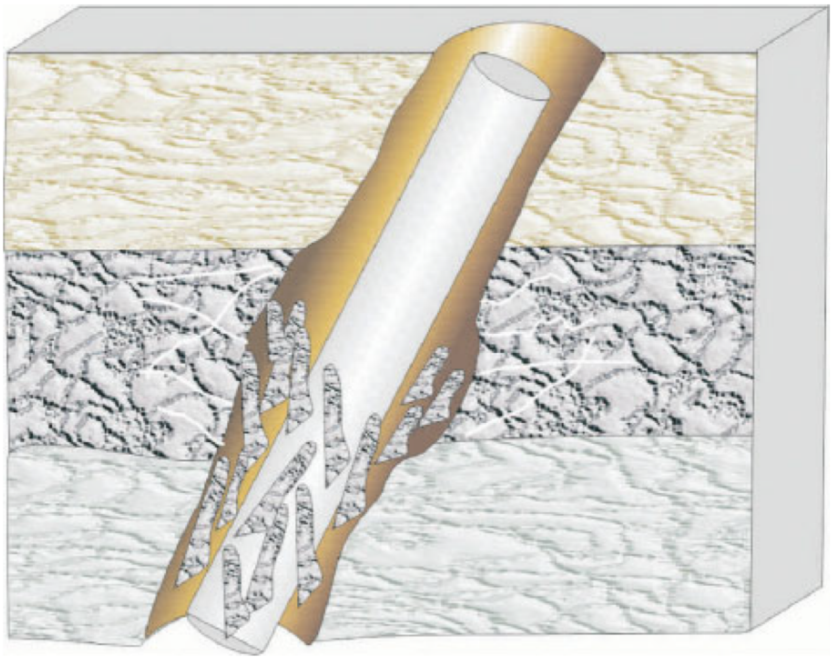


Figure 26: Drilling through tectonically stressed formations (from Pašić et al., 2007)

2.19 Drilling through a mobile formation

Another category is the mobile formation. Mobile formation is caused by overburdened pressure that squeezes shale and/or salt into a wellbore. Mobile formations behave in a plastic manner, deforming under pressure. The squeezed formations reduce wellbore diameter; therefore, the drill string/BHA gets stuck inside the wellbore. The deformation results in a decrease in the wellbore size, causing problems of running BHA's, logging tools and casing (Figure 27).

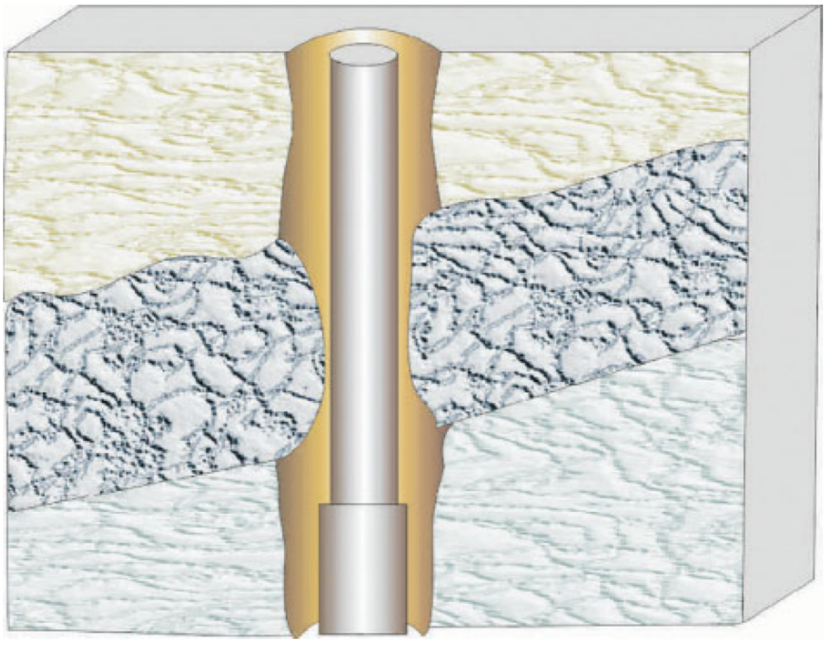


Figure 27: Drilling through a mobile formation (from Pašić et al., 2007)

It could happen at anytime as drilling, tripping in and tripping out depending on how fast plastic formations are moved (Abduljabbar et al., 2018). Over pull, down weight and torque are suddenly increased. Most of the time, the BHA gets stuck at the plastic zones because BHA contains the largest diameter component. A deformation occurs because the mud weight is not sufficient to prevent the formation squeezing into the wellbore.

2.20 Drilling through a naturally overpressured shale

Naturally overpressured shales are most commonly caused by geological phenomena such as undercompaction, naturally removed overburden and uplift (Figure 28). Using insufficient mud weight in these formations will cause the hole to become unstable and collapse. The short time hole exposure and an adequate drilling fluid weight can help to stabilize these formations.

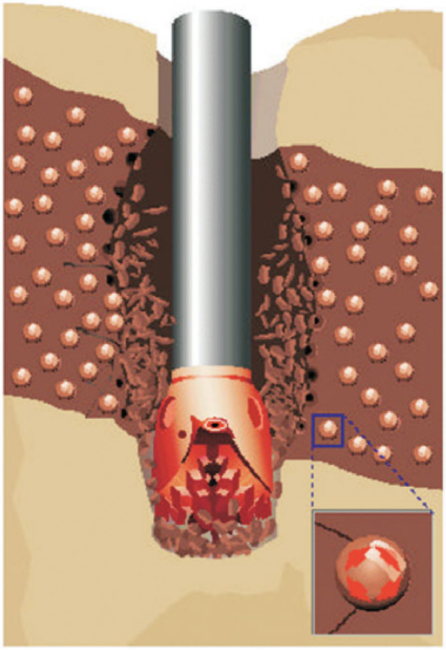


Figure 28: Drilling through a naturally overpressured shale

2.21 Drilling through induced over-pressured shale

Induced over-pressured shale collapse occurs when the shale assumes the hydrostatic pressure of the wellbore fluids after a number of days exposure to that pressure. If the pressure conditions are not changed, the shale collapses in a similar manner to naturally overpressured shale (Figure 29). This mechanism normally occurs in water-based drilling fluids, after a reduction in drilling fluid weight or after a long exposure time during which the drilling fluid remained stagnant.

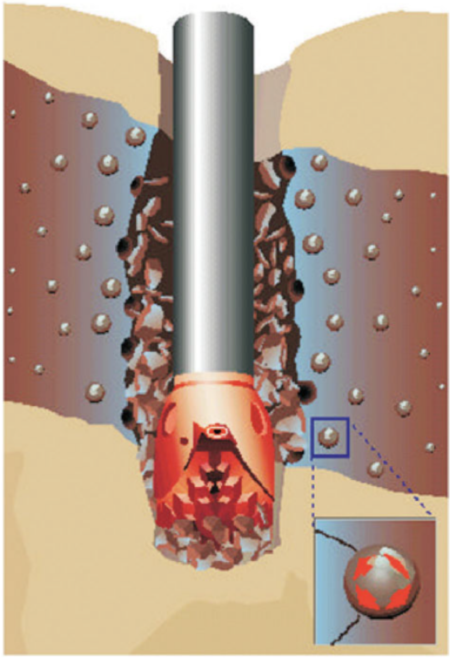


Figure 29: Drilling through induced over-pressured shale

3 Methodology

3.1 Creating & listing the drilling problems and indicators

In order to use the filtration method, a series of data is necessary. This data is meticulously created through the application of the theory section described in this article, which involves careful consideration of each variable change experienced during drilling problems.

Therefore, using excel, a dataframe including all the problems listed (same problems mentioned in the theory part of this article) was created. The Excel sheet is a table that provides information about drilling problems that are categorized into different sections, and for each problem, there are indicators listed based on surface data and downhole data. Here's a breakdown of the columns in the Excel sheet:

1. Problem: This column lists different drilling problems that can occur during drilling operations, such as ”Sour Gas Bearing Zones,” ”Shallow Gas-Bearing Zones,” ”Stacked Tools,” ”Bit Balling,” etc.

2. Indicator (From Surface Data): This column provides indicators related to the drilling problem, based on surface data. The indicators in this column represent variables like return rate, SPP (Standpipe Pressure), flow rate, torque, RPM (Rotations Per Minute), hook load, amount of cuttings, mud density, mud viscosity.

3. Indicator (From Downhole Data): This column provides indicators related to the drilling problem, based on downhole data. The indicators follow the same notation as the previous column, representing variables like torque, RPM, pressure, temperature, and ROP.

The purpose of this Excel sheet is to document the drilling problems and associated indicators, both from surface and downhole data. It can be used as a reference or tool for analyzing drilling operations, identifying potential problems, and understanding the impact on various parameters during the drilling process.

The Indicators from the surface and downhole data, as well as their changes based on the theory part, are listed for each problem. The indicators are represented by arrows pointing upwards (↑) for increase, downwards (↓) for decrease, and a hyphen (-) for unchanged or negligible change. Double arrows (↑ or ↓ then -) suggest that the variable may undergo an increase or decrease before returning to its original value. Additionally, the ”uncontrolled” sign is specific to the ’ROP’ variable and denotes a heavily unusual change, typically occurring when encountering shallow gas or sour gas bearing zones. The dataframe will be used for further filtration purposes, which are explained in section 3.2. The information behind the selection of the indicators are also explained in the theory part of this article.

The reason behind the duality of the indicator sources (surface and downhole) is the assumption of having two different measurement points, one traditional checkpoint in the surface as well as one along the drillstring. This is important, as the modern ASM technology allows us to implement nodes in a variety of lengths along the drillstring, which means a more comprehensive understanding of the measurements that are essential to an early detection of drilling problems using this program, as well as the future endeavours that use this program as a basis.

Afterwards, using the Pandas package, the Excel table is converted to a python format, which would subsequently be used in the program's code. This conversion allows for easier data manipulation and analysis within the Python programming environment.

To begin this process, the Pandas package needs to be imported. This is done by including the line ”import pandas” at the beginning of the program. This imports all the necessary functions and classes from the Pandas library that will be used to handle Excel data.

Once the Pandas package is imported, the next step is to read the Excel file. This is accomplished using the ”read_excel()” function provided by Pandas. The function takes the name or path of the Excel file as its parameter. It reads the file and stores its contents in a Pandas DataFrame, which is a two-dimensional tabular data structure that can hold heterogeneous data. This DataFrame can then be accessed and manipulated using various Pandas functions and methods.

Once the data is loaded into the DataFrame, it can be displayed to verify its contents. This is often done using the ”print()” function, which outputs the DataFrame to the console. This data is further implemented in the very beginning of the program's code.

The tables presented below represents the said dataframe in the Excel file:

Problem		
Problems Associated with Drilling Operations	Sour Gas Bearing Zones	
	Shallow Gas-Bearing Zones	
	Stacked Tools	
	Resistant Beds Encountered	
	Bit Balling	
	Formation Cave-in	
Problems Related to the Mud System	Drilling Fluid and its Problems	Lost Circulation
		Mud Contamination
		Poor Hole Cleaning
		Drilling Fluid Backflow
Problems Related to the Mud Hydraulics	Borehole Instability	Hole Enlargement (Washout)
		Hole Closure (Creep)
		Fracturing
		Collapse and Burst
	Stuck Pipe	Problems Related to Stuckpipe
		Mechanical Pipe Sticking
Well Control and BOP Problems	Kicks	
Drillstring and Bottomhole Assembly Problems	Drillpipe Failures	Tension Load
		Fatigue
	Failures Caused by Downhole Friction Heating	Heat Check Cracking
		Ductile and Brittle Fractures
	Vibration Induced Anomalies	Axial Vibrations
		Torsional Vibrations
		Lateral/transverse Vibrations
	Drillstring Failures	
	Drill Bit Jamming	
	Twist-off	
Wellbore Instability Problems	Drilling through naturally fractured or faulted formations	
	Drilling through tectonically stressed formations	
	Drilling through a mobile formation	
	Drilling through a naturally overpressured shale	
	Drilling through induced over-pressured shale	

Table 1: The dataframe in full resolution - Problems

Indicator (From Surface Data):									
Surface Tank Volume (Pit Volume)	Return Rate	SPP	Flow Rate	Torque	RPM	Hook Load	Amount of Cuttings	Mud Density	Mud Viscosity
↑	↑	↑	↓	-	-	-	-	-	-
↑	↑	↑	↓	-	-	-	-	-	-
↓	↓	↓	↑	-	-	↓	-	-	-
-	-	↑	-	-	↓	-	-	-	-
-	-	↑	-	-	↓	↑	-	-	-
-	↓	-	↓	-	-	-	↑	-	-
↓	↓	↓	↑	-	-	-	-	-	-
-	-	-	-	-	-	-	-	↑	↑
↑	↑	↑	↓	↑	↓	-	-	-	-
↑	↑	↑	↓	-	-	-	-	-	-
-	-	-	-	-	-	-	↓	-	-
-	-	↑	-	↑	-	-	-	-	-
↓	↓	↑	↑	-	-	-	-	-	-
↑	↑	↑	↓	↑	-	-	-	-	-
-	-	-	-	↑	↓	-	-	-	-
-	-	↑	-	↑	↓	-	-	-	-
↑	↑	↑	↓	-	-	↓	-	↓	↓
-	-	-	↑ or ↓ then -	-	-	-	-	-	-
-	-	-	↑ or ↓ then -	-	-	-	-	-	-
-	-	-	↑ or ↓ then -	-	-	-	-	-	-
-	-	-	↑ or ↓ then -	-	-	-	-	-	-
-	-	-	-	-	↓ then ↑, repeatedly	-	-	-	-
-	-	-	-	-	↓	-	-	-	-
-	-	-	-	↑	↓	-	-	-	-
↓	↓	↓	↑	-	↑	-	-	-	-
-	-	-	-	-	↓	-	-	-	-
↓	↓	↓	↑	↑	↑	-	-	-	-
↑	↑	↑	↓	↑	-	-	-	-	-
↑	↑	↑	↓	↑	-	-	-	-	-
-	-	↑	-	↑	-	-	-	-	-
↑	↑	↑	↓	↑	-	-	-	-	-
↑	↑	↑	↓	↑	-	-	-	-	-

Table 2: The dataframe in full resolution - Indicators (From Surface Data):

Indicator (From Downhole Data):				
Torque	RPM	Pressure	Temperature	ROP
-	-	↑	-	uncontrolled
-	-	↑	-	uncontrolled
↓	↓	↓	-	↓
-	↓	↑	-	↓
-	↓	↑	-	↓
-	-	-	-	-
-	-	↓	-	-
-	-	-	-	-
↑	↓	↑	-	↓
-	-	↑	-	-
-	-	-	-	-
↑	-	↑	-	-
-	-	↑	-	-
-	-	↑	-	-
↑	↓	-	-	-
↑	↓	-	-	-
-	-	↑	-	↑
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	↓ then ↑, repeatedly	-	-	-
-	↓ then ↑, repeatedly	-	-	↓
↑	↓	-	-	↓
-	↑	↓	↑	↓
↓	↓	-	-	↓
↑	↑	↓	↑	↓
-	-	↑	-	-
-	-	↑	-	-
↑	-	↑	-	-
-	-	↑	-	-
-	-	↑	-	-

Table 3: The dataframe in full resolution - Indicators (From Downhole Data):

3.2 Introduction to the program and the code

The reason for the creation of this program is the double-sided filtration it offers. The program has two distinct parts: in the first part, if the user inputs signs, and they will receive the problem(s) detected. This filtration process narrows down the focus to relevant drilling issues. Conversely, the second part of the program reverses the filtration by allowing the user to input specific drilling problems and obtain corresponding signs. This versatility enables a comprehensive analysis of drilling problems and their associated indicators.

The code is designed to create a Graphical User Interface (GUI) application using the Tkinter module in Python. The GUI consists of a window with two tabs: ”Drilling Problem Detector” and ”Anomaly Detector.” It provides a powerful and efficient solution for real-time drilling problem detection and analysis, incorporating the theory discussed in the previous chapter.

All the signs retrieved from a dataframe previously created in an Excel file, alongside their data, have been imported into this code. These signs represent specific parameters related to drilling operations, such as surface tank volume, return rate, SPP (Standpipe Pressure), flow rate, torque, RPM, hook load, amount of cuttings, mud density, and mud viscosity. The values in the dataframe correspond to different points in time and indicate the direction of change in each variable—up (↑), down (↓), or horizontal (-). Double arrows (↑ or ↓ then -) suggest that the variable may undergo an increase or decrease before returning to its original value. Additionally, the ”uncontrolled” sign is specific to the ’ROP’ variable and denotes a heavily unusual change, typically occurring when encountering shallow gas or sour gas bearing zones. This wide range of options allows for the easier detection of more complex drilling problems.

The code imports several Python libraries and modules, including pandas, tkinter, messagebox, ttk, and Python Imaging Library (PIL). The pandas library is utilized for data manipulation, analysis, and visualization, while tkinter provides a toolkit for building graphical user interfaces. The messagebox module is employed to display custom messages and buttons within the GUI. The ttk module enhances the GUI-building process by offering more advanced widgets and styles. Lastly, the PIL library is used for image manipulation within the application. The inclusion of these libraries ensures that the code is not only efficient and effective but also scalable and flexible.

The application’s user-friendly interface allows users to easily filter and display drilling problems based on changes in variables related to drilling operations. It consists of two tabs: ”Drilling Problem Detector” and ”Anomaly Detector.” The first tab allows users to filter a dataframe based on their input and displays the drilling problem(s) in a labeled area. The second tab, designed for drilling problem analysis, functions similarly to the first one but with changes in the indicators being shown as the result, while the drilling problems are given as input.

To facilitate user interaction, the code creates six drop-down menus for each tab, each labeled and offering various options. The selected value from each drop-down menu is stored in StringVar() objects named var1 to var6. These selections contribute to the filtration and analysis process, allowing users to specify their criteria effectively.

In addition, the code creates two frames within the GUI window and sets background images for each frame using the Tkinter PhotoImage class. A Combobox is also created, displaying a list of drilling problems as options. These options are stored in a list called options7. The Combobox's style is customized, and a callback function is added to display specific information related to the selected drilling problem.

When an option is selected from the Combobox, the submit_callback2() function is triggered. This function retrieves the corresponding data from a dataframe called df2 and displays the information in a label widget named result_label2. The displayed information includes surface tank volume, return rate, standpipe pressure, flow rate, torque, and other relevant drilling metrics.

In summary, this application serves as an excellent example of the power and flexibility of Python in creating robust and user-friendly applications for real-time drilling problem detection and analysis. Its user-friendly interface, comprehensive data analysis and visualization capabilities, and efficient utilization of Python libraries and modules make it an indispensable tool for professionals working in the drilling industry. By incorporating the theory discussed in the accompanying article, this code demonstrates the incredible possibilities of Python and showcases the power of GUI programming with Tkinter.

3.3 Initiating a filtration program: Drilling Problem Detector

For this matter firstly the ”Drilling Problem Detector” tab is opened; Then, the concerning indicators as well as their corresponding changes are picked, and finally the ”Submit” button at the very bottom is selected. In order for the program to work, a minimum of one indicator must be selected.

For example, when a situation (i.e. a kick) is encountered, the return flow rate will increase:

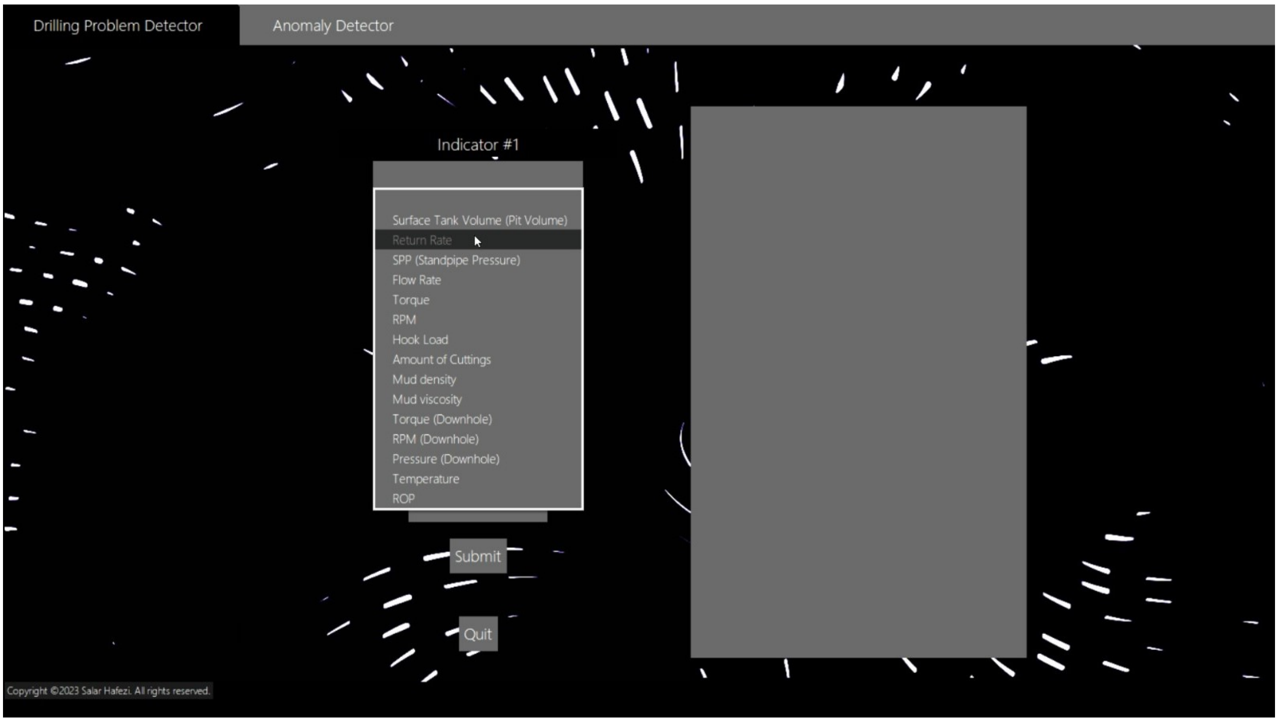
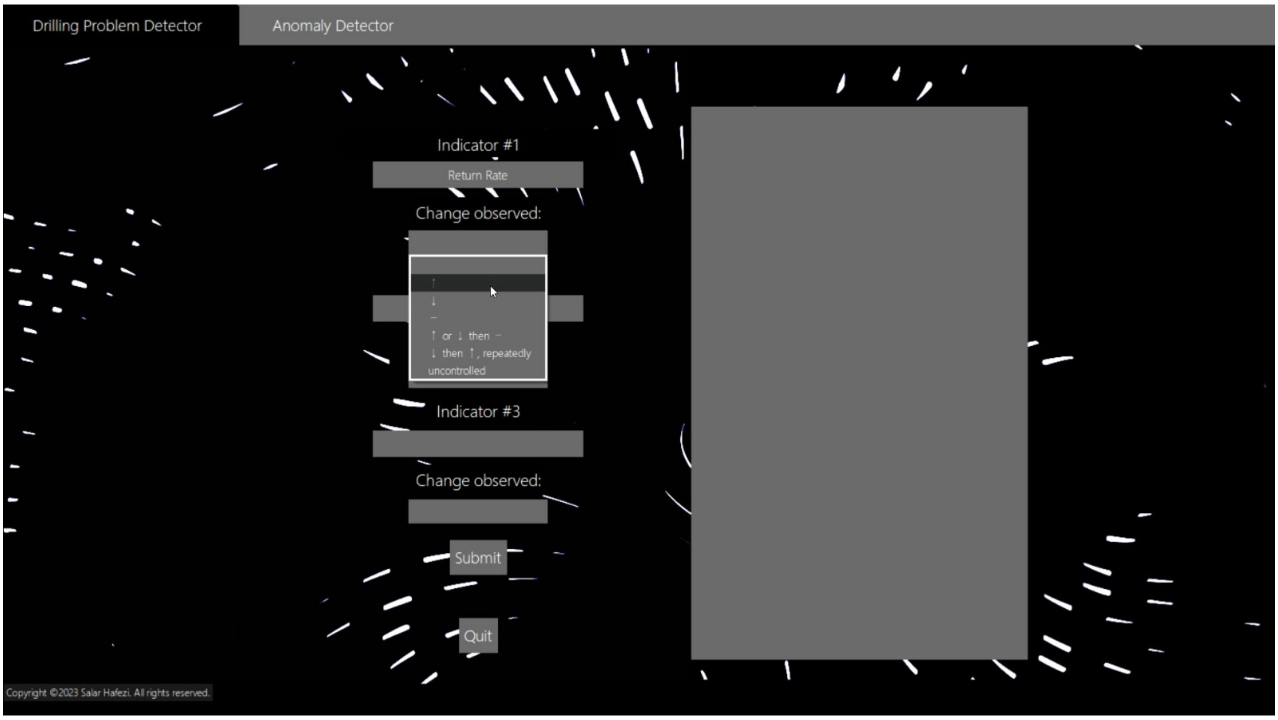


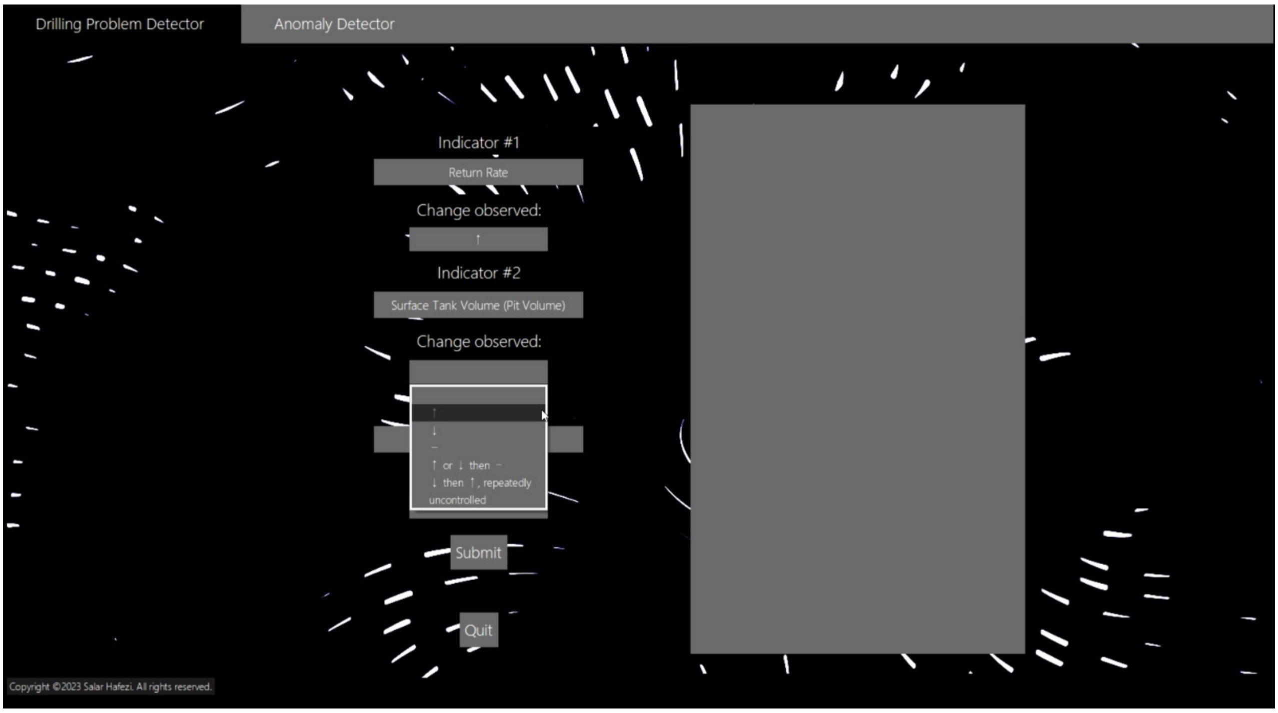
Figure 30: Choosing the first indicator



Indicator #1
Return Rate

Figure 31: Selecting the change observed from the first indicator

And so does the surface tank volume (pit volume):



Indicator #1: Return Rate

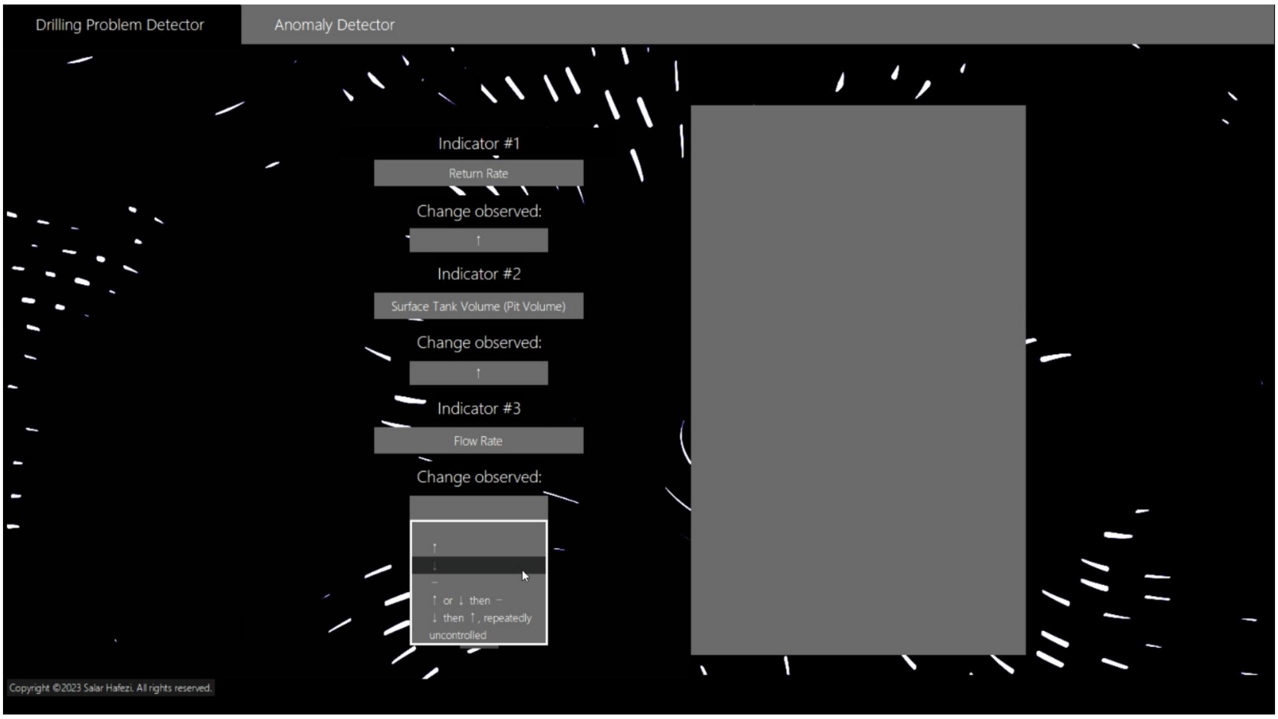
Change observed: ↑

Indicator #2: Surface Tank Volume (Pit Volume)

Change observed:

Figure 32: Choosing the second indicator

While the pumping flow rate is going down (flowing well with pump shut off):



Indicator #1: Return Rate

Change observed: ↑

Indicator #2: Surface Tank Volume (Pit Volume)

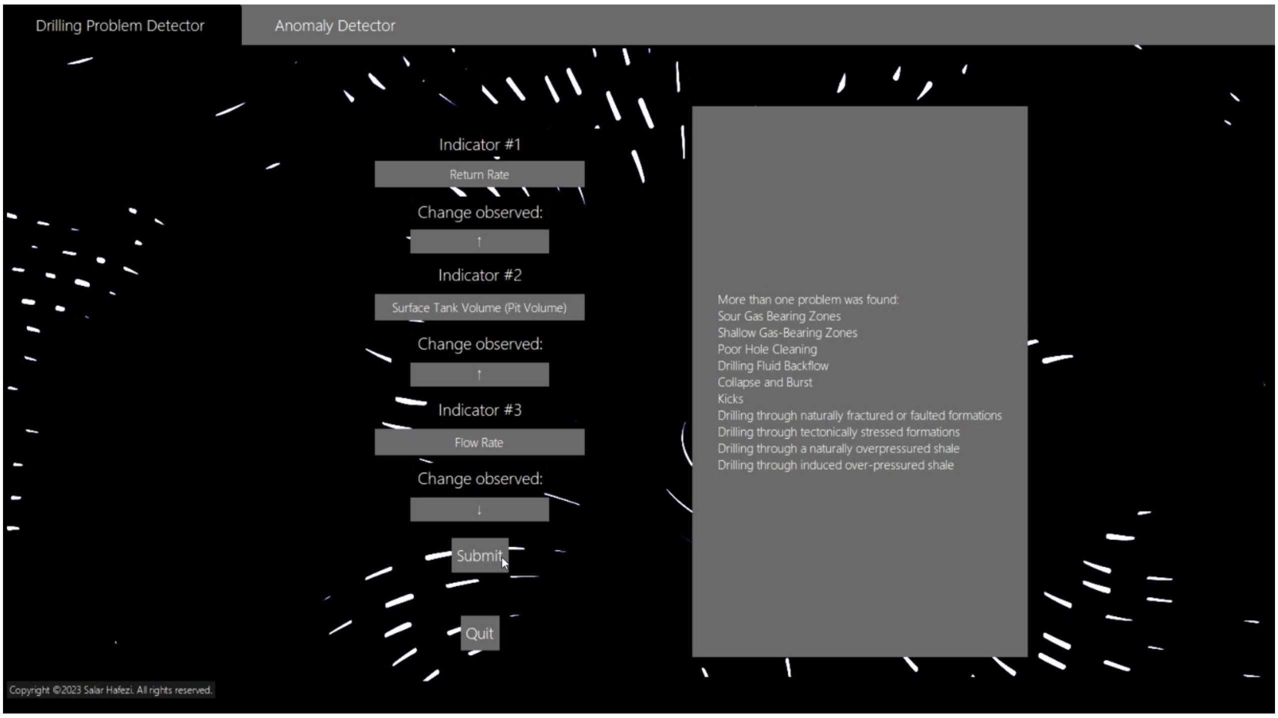
Change observed: ↑

Indicator #3: Flow Rate

Change observed:

Figure 33: Choosing the last indicator

After pressing the submit button, the corresponding problem(s) will be shown in the box in front of the selection menu:



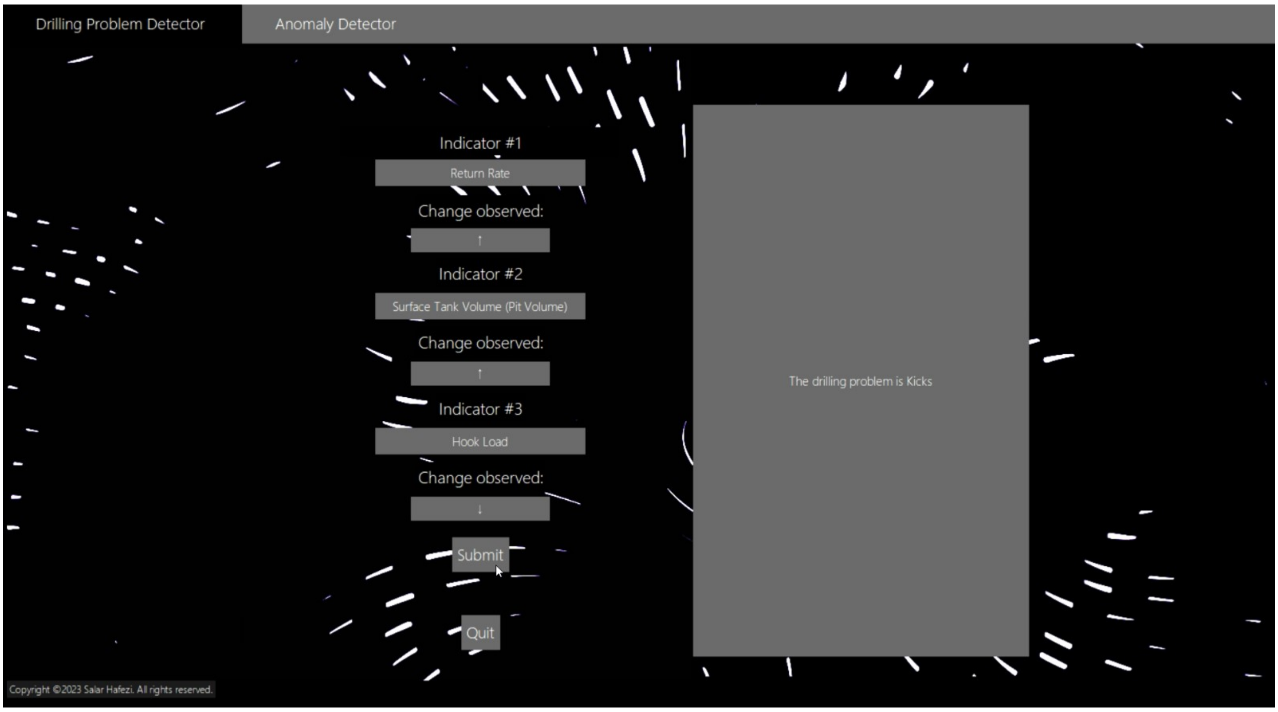
Indicator #1: Return Rate
Change observed: ↑
Indicator #2: Surface Tank Volume (Pit Volume)
Change observed: ↑
Indicator #3: Flow Rate
Change observed: ↓

More than one problem was found:
Sour Gas Bearing Zones
Shallow Gas-Bearing Zones
Poor Hole Cleaning
Drilling Fluid Backflow
Collapse and Burst
Kicks
Drilling through naturally fractured or faulted formations
Drilling through tectonically stressed formations
Drilling through a naturally overpressured shale
Drilling through induced over-pressured shale

Figure 34: Filtration using three indicators: Return rate, pit volume and the pumping flow rate.

As observed in the result box, even though these are the primary indicators of a kick, they are still quite identical to other problems such as shallow gas encounter. This is where the more specific indicators step in.

Whilst changes in pump pressure don't quite assist with the determination of the problem, surface indicators such as reduction in drillpipe weight or downhole signs such as a drilling break (sudden increase in ROP) will make kick stand out as a problem, leading to the determination of the issue in a split second:



Indicator #1
Return Rate
Change observed:
↑
Indicator #2
Surface Tank Volume (Pit Volume)
Change observed:
↑
Indicator #3
Hook Load
Change observed:
↓

The drilling problem is Kicks

Figure 35: Detection of the problem using another third indicator (hook load). The Last indicator (Flow rate) was replaced, subsequently, as it barely influenced the filtration.

3.4 Initiating a filtration program: Anomaly Detector

This filteration program allows the engineers to understand the changes observed from the variables measured during drilling operations, when a drilling problem arises. In order to do that, firstly the ”Anomaly Detector” tab must be selected:

Figure 36: Selecting the tab

Afterwards, and by clicking on the combobox below the ”Drilling Problem” section, a variety of drilling problems are presented. Then, the drilling problem to analyze is selected. In this instance, ”Kicks” is going to be that problem:

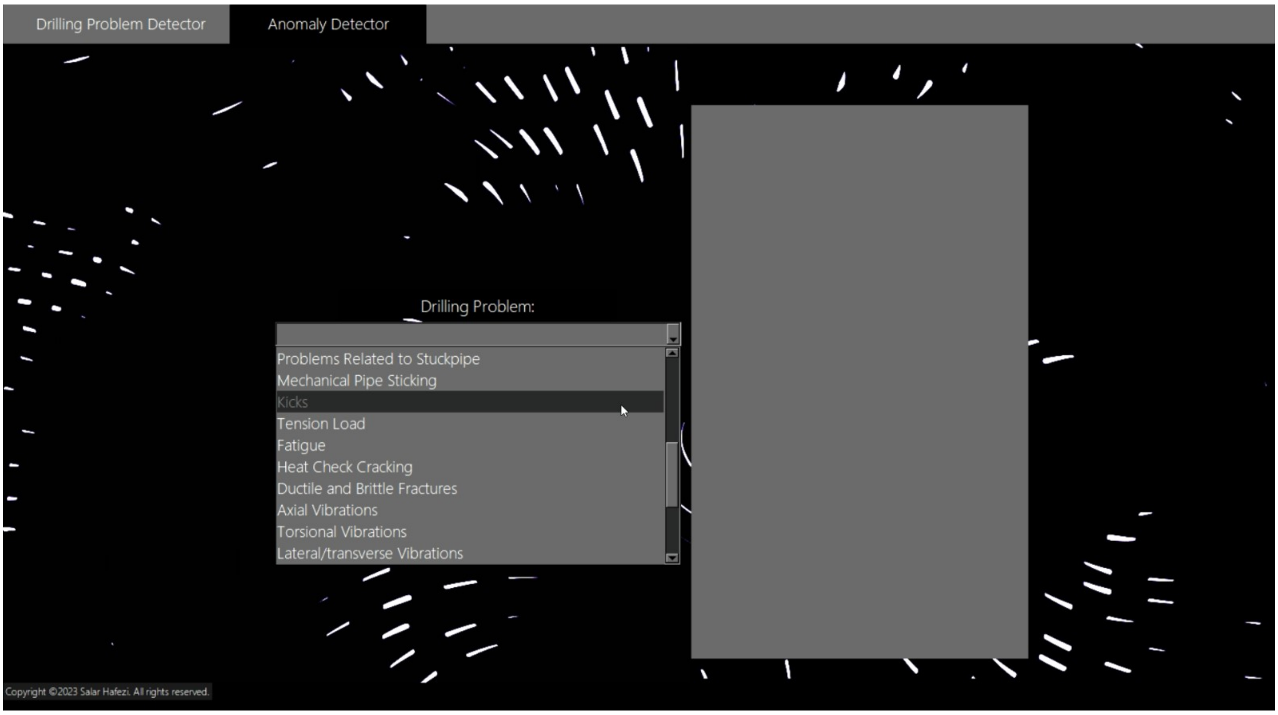
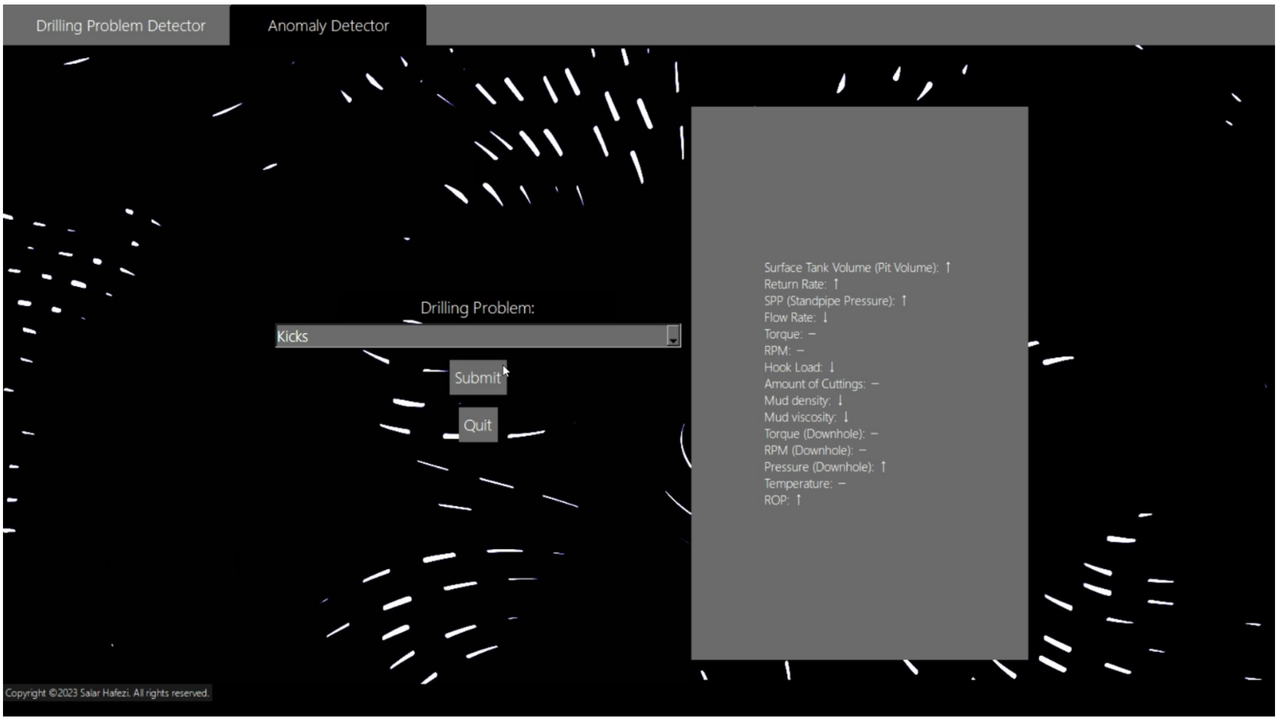


Figure 37: Selecting the drilling problem

Finally, after clicking on the submit button, the anomalies and changes in each measured indicator during that specific problem (which on this case is kicks) will be shown in the result box in front of the selection menu:



Drilling Problem: Kicks

Surface Tank Volume (Pit Volume): ↑
Return Rate: ↑
SPP (Standpipe Pressure): ↑
Flow Rate: ↓
Torque: –
RPM: –
Hook Load: ↓
Amount of Cuttings: –
Mud density: ↓
Mud viscosity: ↓
Torque (Downhole): –
RPM (Downhole): –
Pressure (Downhole): ↑
Temperature: –
ROP: ↑

Figure 38: Anomalies shown as a result of filtration

3.5 Future work

The outlined and detailed code elucidated within the confines of this article serves as an invaluable cornerstone, upon which the edifice of future endeavors can be firmly erected. Its profound significance lies in its ability to function as a bedrock, fostering the development of advanced systems and pioneering innovations. It can act as a basis for algorithms that could identify patterns, detect deviations from normal behavior, and generate alerts for drilling personnel to take necessary actions. The oil and gas industry constantly strives for improved operational efficiency, reduced costs, and enhanced safety in drilling operations. The ability to detect drilling problems promptly is crucial for maintaining optimal drilling performance.

Throughout the history of hydrocarbon drilling, various methods have been developed to detect unintended flow interaction between well and formation as fast as possible to take immediate action and handle the problem. Still, pit gain or loss, and unexpected deviations in pump pressure, are used as primary indicators for kick or lost circulation. However, for long wells and in particular High Pressure High Temperature wells, these indicators may be too rough for fast and precise detection of small and moderate volumes ,hindering real-time analysis and decision-making. Various logging tools, collectively referred to as logging while drilling (LWD), are embedded into the bottomhole assembly. Although these measurements are fairly accurate, the transmission bandwidth is often insufficient for most applications. Traditionally, mud pulse telemetry has been used to transmit LWD data to the rig in real time. The bandwidth of mud pulse telemetry is typically in the range of 10–40 Bits per Second (bit/sec) but can drop to as low as 0.5 bit/sec in long wells (Wasserman et al. 2008). Either way, it is too low for kick and loss detection.

As an alternative, wired-pipe technology (Gravdal et al. 2010a; Rasmus et al. 2013; Schils et al. 2016) offers bandwidths up to 1 Megabits per Second (Mbit/sec). However, possibly because of the high cost and complexity of deployment, this technology has so far seen limited use.

However, another interesting application of wired drillpipe is along-string pressure sensing where pressure sensors are installed at a fixed interval inside the annulus. The advent of Along String Measurements (Along String Measurements (ASM)) has revolutionized the way field data is collected and utilized. This section explores the potential of ASM in harnessing real-time field data for effective drilling problem detection and subsequent mitigation. The data provides great insight into the hole conditions along the drill string andat the bottom hole assembly (BHA). Based on this insight, drilling parameters at surface can be accurately adjusted, resulting in increased overall efficiency.

3.5.1 Real-Time Field Data Utilization

The innovation of transmitting real-time downhole data to the surface gave rise to the emergence of the measurement-while-drilling (MWD) oilfield service industry. The initial telemetry technologies that facilitated MWD services were mud-pulse, electro-magnetic, and acoustic methods. These methods varied in their effectiveness, with successful data transmission depending on environmental factors. Mud pulse telemetry utilized drilling fluid in the pipe bore, but its feasibility could be hindered by factors such as the rheological properties of the fluid, such as the use of foam. Electro-magnetic telemetry relied on signal transmission through the earth, with limitations imposed by depth, formation resistivity, and mud resistivity. Acoustic telemetry utilized the drillstring as a channel but suffered from signal attenuation due to contact between the pipe and borehole wall.

On the other hand, wired pipe telemetry employed a dedicated cable within the drillpipe, which provided a reliable conduit for data transfer, unaffected by environmental concerns. However, this approach involved a cable running through the drillstring, necessitating multiple couplers to bridge the signal across drillpipe tool joints. The use of numerous electrical and mechanical components in this setup raised concerns regarding the reliability of the components and the overall system.

Initially, real-time telemetry systems were primarily developed for directional drilling applications, driven by the need to minimize non-productive time. Prior to the advent of MWD, conducting a directional survey involved pausing drilling operations, securing the pipe, and deploying a survey tool using a slick-line or by dropping it down the borehole, which was time-consuming and prone to failure. The introduction of MWD enabled the integration of formation evaluation sensors and systems, which presented challenges in terms of developing sensors and measurement technologies capable of withstanding the harsh downhole environment characterized by high vibration, pressure, and temperature. Nevertheless, these sensor systems facilitated the creation of high-quality wellbores that delivered value to clients, even in complex drilling scenarios where substantial producible intervals were sought after.

Telemetry technologies played a pivotal role in transmitting formation evaluation logs while drilling, known as logging-while-drilling (LWD), allowing for real-time decision-making and reservoir appraisal. In recent times, the volume of downhole data available for transmission has surpassed the capacity provided by conventional telemetry technologies, resulting in partial or intermittent real-time data transmission. Full data sets are only recovered when the downhole tool returns to the surface.

In recent years, two significant technological advancements have emerged: drilling systems automation (Drilling Systems Automation (DSA)) and wired-pipe technology. DSA involves automating systems from the drill bit to the enterprise, relying on a digital infrastructure. Wired pipe technology provides the necessary digital backbone to support DSA and advanced MWD/LWD services. Finally there is the ASM, or Along String Measurement, which refers to a specific measurement technique or system that involves placing sensors or instruments at various points along the drillstring. These sensors can capture data related to drilling parameters, such as weight on bit, torque, vibration, or other downhole conditions. ASM allows for more detailed and localized measurements along the drillstring, providing valuable information for monitoring drilling operations and optimizing performance.

3.5.2 Wired Drill Pipe

The utilization of a wired drillstring for telemetry and power predates the establishment of the measurement-while-drilling (MWD) industry. According to Arps and Arps (1964), who discussed mud pulse telemetry, a wired drillstring was developed in the 1930s. This system employed insulated conducting rods in each section of the drillpipe, creating an electrical conduit to the surface. Another system from the late 1930s involved drillpipe with embedded electrical cables and specialized connectors.

Dennison (1979) described a wired pipe telemetry system that incorporated unique drillpipe joints from the surface to an intermediate position, with an armored cable jumper continuing down. The inter-pipe coupling was galvanic, and the system achieved a data rate of 36 kbps. Wolf et al. (1985) used this wired telemetry system to obtain high-speed measurements of downhole forces, accelerations, pressures, and formation properties. Aarrestad et al. (1986) discussed a wired cable system for testing, comprising a side-entry sub on the surface and a wet-connect system downhole. Fay et al. (1992) and Pavone and Desplans (1994) presented the IFP Trafor system, which reached a capacity of 30 kbps. This system employed wired drillpipe from the surface to an intermediate position, and an electrical cable within the lower drillpipe and bottomhole assembly for transmission.

Abyzbayev et al. (1997) introduced the Russian electric drilling system, capable of providing power to a downhole motor and transmitting data to the surface. The cable was centrally located in the drillpipe joint, and its connection was galvanic. However, reliability issues hindered the system's performance.

In the early 2000s, the development of a commercial wired pipe concept took place, employing inductive couplers and repeaters. Reeves et al. (2006) discussed the technology and its initial test deployments, while Wolter et al. (2007) detailed its first offshore deployment in the Norwegian North Sea. This system offered a high-speed, bi-directional transmission between downhole and surface, with a data payload of 57.6 Kilobits per second (kbps). Compared to other technologies like mud pulse, electromagnetic, and acoustic, this system was at least 1,000 times faster. Notably, it provided an independent data channel that was not influenced by the fluid-filled pipe bore or the formation, making it viable for various drilling operations.

The wired drillpipe (Wired Drillpipe (WDP)) network comprises modified conventional drilling tubulars, incorporating a low-loss data cable running the length of each joint. Unique inductive coils installed in the pin nose and box shoulder of each connection transmit data across the tool joint interface. Second-generation, double-shoulder connection configurations provide an ideal location for coil placement, with each coil installed in a protective groove in the secondary torque shoulder. Figure 39 illustrates a coil installed in the pin end of a drill pipe joint.

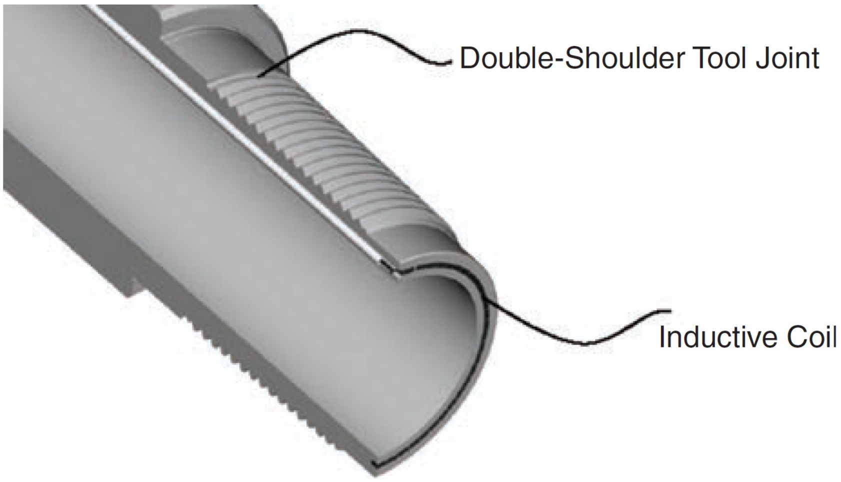


Figure 39: Schematic of Double-Shouldered Pin Tool Joint showing the location of Inductive Coil

When two connections are joined together, the pin end coil of one joint comes into close proximity with the box end coil of another joint. These coils are designed in a circular shape and do not require any specific orientation during assembly. An alternating current flows through the coil in either segment, creating a changing electromagnetic field. This field induces current flow in the other coil, allowing the transmission of signals between the two joints. The data cable is enclosed within a pressure-sealed conduit made of stainless steel. In the configuration of a drill pipe, this conduit passes through the tool joint body and enters the internal diameter of the drill pipe at the internal upset. For clarity, refer to Figure 40, which provides a cutaway view illustrating the placement of the inductive coils and conduit in a fully assembled drill pipe connection.

The conduit remains under tension within the drill pipe tube, securing its position against the tube wall in most conditions and minimizing any interference with mudflow or the deployment of tools through the center of the assembly. In situations where signal amplification is necessary, a pre-assembled booster drill pipe joint can be inserted into the drill string. These booster joints consist of a 4 Feet (ft) long sub that contains an electronics package powered by a lithium battery. They are threaded at the bottom of a specially manufactured 27 ft drill pipe joint. Consequently, the overall length of the complete booster assembly is 31 ft and appears to rig personnel as a standard Range 2 drill pipe joint with an extended length lower tool joint.

The overall design of the drill pipe and tool joint is intended to seamlessly integrate into regular rig operating procedures. No special handling or assembly protocols are required, and any thread compound chemistry can be used. While the make-up torque for double-shouldered connections is higher compared to standard American Petroleum Institution (API) connections, intelligent tubulars exhibit identical mechanical and hydraulic performance to non-wired double-shouldered drilling tubulars. Furthermore, the simplicity of the design allows for the adaptation of other commonly used drilling tubulars to support data transmission. Various equipment, such as heavy-weight drill pipe, drill collars, drilling jars, string stabilizers, and roller reamers, all equipped with modified double-shouldered connections, have been successfully integrated into the network.

For more detailed information on the underlying network technology, please refer to Society of Petroleum Engineers (SPE) Paper 92477 titled ’Intelligent Drill String Field Trials Demonstrate Technology Functionality,’ presented at the SPE/International Association of Drilling Contractors (IADC) Drilling Conference in 2005.

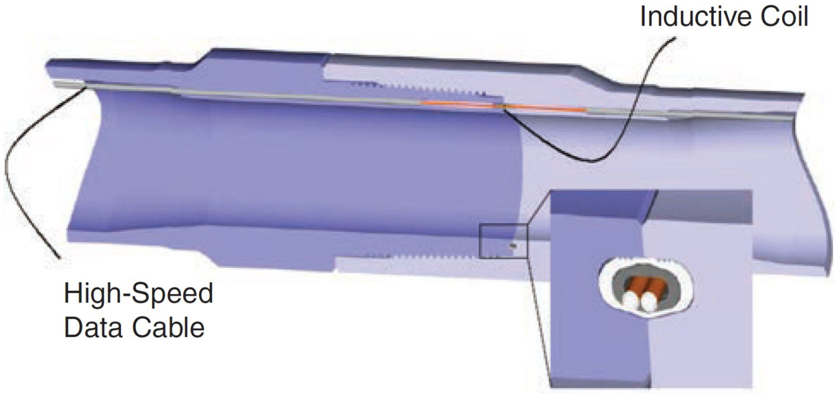


Figure 40: Schematic of Made-Up Drill Pipe Tool Joint Connection showing the location of Inductive Coils and Data Conduit

3.5.3 Understanding ASM

The along-string measurement (ASM) tools include a high frequency sensors package that allows for collection of annular and internal pressures, temperature, rotation and three-axis vibrations measurements. along the drill string. Any number of ASM tools can be included in the drillstring, in addition to or replacing repeater subs. As part of WDP, along-string measurement subs (ASM) are equipped with temperature, annular/internal pressure, rotation and vibrations sensors. Data is transmitted to surface at high speed and is available in real-time, even when flow is off. Large data amounts can be communicated to and from surface with negligible time delay and independent from fluid circulation. Displaying the downhole measurements in real-time, both at the rig site and in remote operations centers has proven essential when optimising well construction activities. ASM systems provide a wealth of real-time information, allowing for the detection of subtle changes and anomalies in drilling indicators.

The WDP system is equipped with high-speed telemetry (High-Speed Telemetry (HST)) capabilities. The technical details of this technology have been extensively documented in various papers and articles, most notably Pixton et al's publication in 2014. Figure 41 provides an overview of the system for reference. It comprises a linear network configuration that includes the following components:

- Interface Sub: This component facilitates bidirectional communication with the measurement/-logging while-drilling (M/LWD) tools.
- Wired Drilling Components: All tubulars, subs, jars, and accelerators within the drill string are wired together to establish communication with downhole equipment.
- Repeater Subs with Downhole Network Electronics: Placed along the drill string at regular intervals, typically every 300 - 400 meters, these repeater subs amplify the signals and ensure their transmission all the way to the surface.
- Modified Top Drive Components with Cabling: These components serve as an interface between the surface acquisition system and the drill stem, enabling data transfer.
- Surface Network and Computer Systems: The WDP system incorporates surface network infrastructure and computer systems to collect and distribute the streamed data effectively.

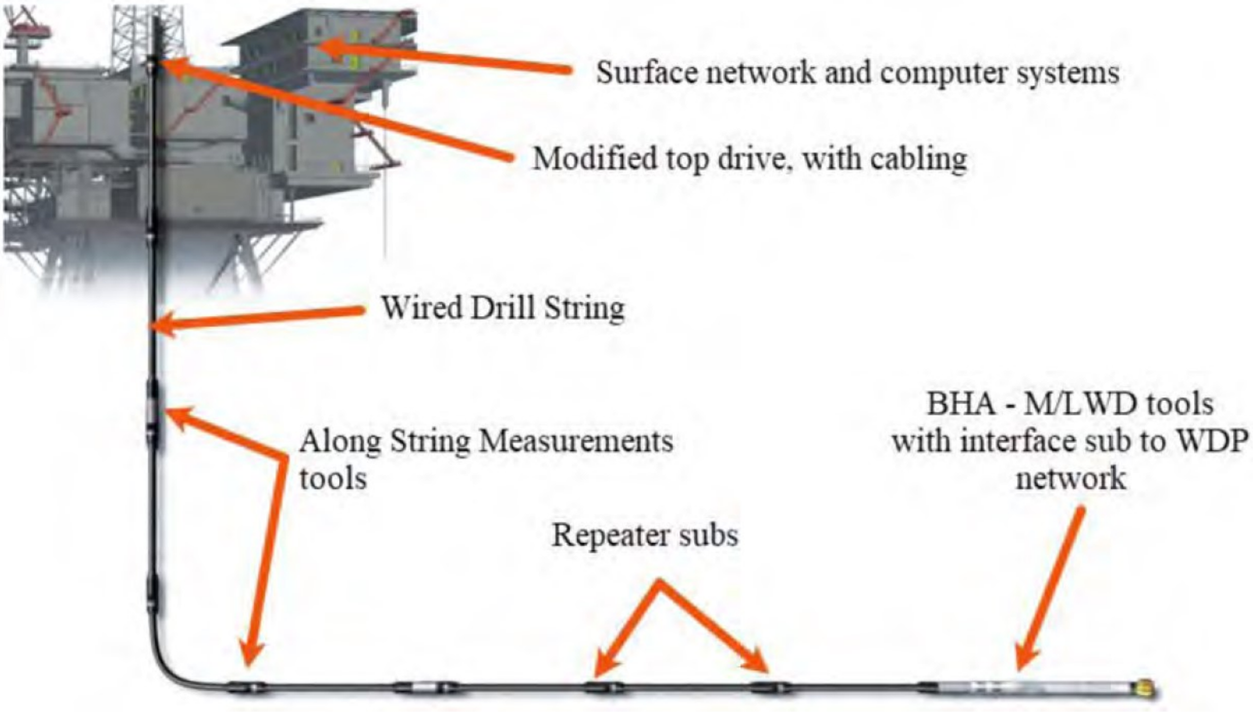


Figure 41: An overview of the wired pipe system components.

3.5.4 Algorithm Development and Code Integration

To effectively utilize ASM data for drilling problem detection using the current code as a cornerstone, the development of robust algorithms and integration with drilling control systems is essential. Advanced machine learning techniques can be applied to ASM data, enabling the creation of predictive models and anomaly detection algorithms. These algorithms can identify patterns, detect deviations from normal behavior, and generate alerts for drilling personnel to take necessary actions.

The utilization of ASM for drilling problem detection offers several benefits, including:

1. Improved Operational Efficiency: Real-time field data utilization empowers drilling engineers to proactively address drilling problems, minimizing non-productive time and enhancing overall drilling efficiency.
2. Enhanced Safety: Early detection of drilling problems through ASM data analysis ensures prompt response, mitigating potential safety hazards associated with equipment failures, wellbore instability, and stuck pipe incidents.
3. Cost Reduction: Timely identification and mitigation of drilling issues prevent costly equipment damage, downtime, and non-productive time, resulting in significant cost savings.

ASM data can be leveraged to detect various drilling problems that arise during the drilling process. For example, the analysis of ASM data can help identify the following issues:

1. Lost Circulation: ASM sensors can detect sudden changes in pressure. Combined with surface indicators such as density and flow rate, it can help with the detection of a potential drilling fluid loss. Real-time data analysis using both ASM and surface data can trigger timely responses to mitigate the issue, preventing formation damage, well instability, and subsequent non-productive time.

2. Bit Wear and Failure: ASM measurements can identify abnormal vibrations, temperature changes, and torque fluctuations, which are often early indications of bit wear or impending failure. Detecting these issues early can lead to proactive measures, such as bit replacement, avoiding costly downtime and potential wellbore complications.

3. Stuck Pipe: ASM data enables the identification of abnormal torque variations, which may signify a stuck pipe situation. Combined with surface data such as WOB, it can result in an early detection which allows for swift action, such as adjusting drilling parameters or employing pipe freeing techniques, minimizing the risk of equipment damage and lost drilling time.

4. Formation Instability: When combined with surface data such as WOB, Changes in torque measurements captured by ASM sensors can indicate formation instability, such as differential sticking or wellbore collapse. Real-time data analysis facilitates prompt decision-making, enabling the implementation of appropriate remedial measures to re-stabilize the wellbore.

5. Kick: Pressure nodes placed along the drill pipe divide the well's annular space into control volumes, allowing flow to be indirectly measured. Each control volume is associated with a pressure sensor node, and the distances between these nodes typically range from 180 to 460 meters. The methodology assumes that changes in flow rate and density within a control volume will result in pressure variations at the nodes. Formation fluid influx, which has a lower density than the drilling mud, can be detected by the decrease in hydrostatic pressure below the fluid front. The pressure above and below the fluid front is influenced by increased friction pressure caused by the influx. To estimate model parameters in real-time, an Unscented Kalman Filter (Unscented Kalman Filter (UKF)) technique is used, which utilizes distributed pressure measurements. The UKF considers uncertainties in both measurements and model parameters and optimizes the estimation based on statistics. By tuning the estimated parameters, a better match between the measured values and the model can be achieved, taking into account measurement uncertainty and assumptions about parameter standard deviations.

By integrating and effectively incorporating the identified abnormalities, as previously highlighted, into the existing program, a multitude of benefits can be achieved. The resulted program not only would function optimally, but would also save significant amounts of time, endure for extended periods, and contribute to environmental preservation. Ultimately, this comprehensive solution has the potential to minimize costs and mitigate losses associated with drilling problems to an unprecedented extent.

4 Conclusion

The potential benefits of this program cannot be overstated. By providing a proactive approach to drilling operations, it can save both time and money while ensuring the safety of all personnel involved. With the ability to anticipate potential problems before they occur, drilling companies can avoid costly downtime, damage to equipment, and even environmental disasters.

The power of this program lies in its ability to quickly and accurately identify potential problems through the use of advanced indicators. By constantly monitoring the drilling operation and analyzing data in real-time, the program can provide valuable insights that allow drilling teams to take corrective action before the situation gets out of hand.

Of course, the effectiveness of the program depends on the quality and comprehensiveness of the indicators it uses. As new technologies emerge and drilling techniques evolve, it is essential to update the program with the latest and most relevant indicators to ensure maximum accuracy and precision.

Finally, the program's inclusiveness is another important factor. By covering all of the major problems experienced in the petroleum industry, it ensures that drilling teams have a comprehensive toolset at their disposal to tackle any challenge that comes their way. And because it is easy to use and integrate into existing drilling operations, it can be a valuable asset for any drilling company looking to improve safety, efficiency, and profitability. Furthermore, ASM technology could provide a valuable opportunity to harness real-time field data for drilling problem detection using this program. By integrating ASM data into drilling control systems and utilizing advanced algorithms, drilling engineers can detect drilling problems promptly, enabling swift mitigation measures. The future of ASM holds great potential for optimizing drilling operations, enhancing safety, and reducing costs in the oil and gas industry.

In summary, this program represents a major step forward for the drilling industry, offering a powerful new tool for anticipating and preventing potential problems before they occur, as well as being a concrete basis for further, more advanced algorithms by being integrated with data attained by the ASM. By providing real-time insights and alerts, it can help drilling companies save time, money, and lives, while ensuring a safer and more sustainable future for the industry as a whole.

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Appendices

Python Code

```
#Importing necessary libraries

import pandas as pd
import tkinter as tk
from tkinter import messagebox
from tkinter import *
from tkinter import ttk
from PIL import Image, ImageTk


# Drilling Problem Detector/Tab1

# Initializing data of lists
data = {'Surface Tank Volume (Pit Volume)': [None, '↑', '↑', '↓', '-', '-', '-', '↓',
'-', '↑', '↑', '-', '-', '↓', '↑', '-', '-', '↑', '-', '-', '-', '-', '-', '-', '-',
'↓', '-', '↓', '↑', '↑', '-', '↑', '↑'],
        'Return Rate': [None, '↑', '↑', '↓', '-', '-', '↓', '↓', '-', '↑', '↑', '-',
        '-', '↓', '↑', '-', '-', '↑', '-', '-', '-', '-', '-', '-', '-', '↓', '-',
        '↓', '↑', '↑', '-', '↑', '↑'],
        'SPP (Standpipe Pressure)': [None, '↑', '↑', '↓', '↑', '↑', '-', '↓', '-',
        '↑', '↑', '-', '↑', '↑', '↑', '-', '↑', '↑', '-', '-', '-', '-', '-', '-',
        '-', '↓', '-', '↓', '↑', '↑', '↑', '↑', '↑'],
        'Flow Rate': [None, '↓', '↓', '↑', '-', '-', '↓', '↑', '-', '↓', '↓', '-',
        '-', '↑', '↓', '-', '-', '↓', '↑ or ↓ then -', '↑ or ↓ then -', '↑ or ↓ then
        -', '↑ or ↓ then -', '-', '-', '-', '↑', '-', '↑', '↓', '↓', '-', '↓', '↓'],
        'Torque': [None, '-', '-', '-', '-', '-', '-', '-', '-', '↑', '-', '-', '↑',
        '-', '↑', '↑', '↑', '-', '-', '-', '-', '-', '-', '-', '↑', '-', '-', '↑',
        '↑', '↑', '↑', '↑', '↑', ],
        'RPM': [None, '-', '-', '-', '↓', '↓', '-', '-', '-', '↓', '-', '-', '-',
        '-', '-', '↓', '↓', '-', '-', '-', '-', '-', '↓ then ↑, repeatedly', '↓',
        '↓', '↑', '↓', '↑', '-', '-', '-', '-', '-', ],
        'Hook Load': [None, '-', '-', '↓', '-', '↑', '-', '-', '-', '-', '-', '-',
        '-', '-', '-', '-', '-', '↓', '-', '-', '-', '-', '-', '-', '-', '-', '-',
        '-', '-', '-', '-', '-', '-'],
        'Amount of Cuttings': [None, '-', '-', '-', '-', '-', '↑', '-', '-', '-',
        '-', '↓', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-',
        '-', '-', '-', '-', '-', '-', '-', '-'],
        'Mud density': [None, '-', '-', '-', '-', '-', '-', '-', '↑', '-', '-', '-',
        '-', '-', '-', '-', '-', '↓', '-', '-', '-', '-', '-', '-', '-', '-', '-',
        '-', '-', '-', '-', '-', '-'],
        'Mud viscosity': [None, '-', '-', '-', '-', '-', '-', '-', '↑', '-', '-',
```

```
        '-', '-', '-', '-', '-', '-', '↓', '-', '-', '-', '-', '-', '-', '-', '-',
        '-', '-', '-', '-', '-', '-', '-'],
        'Torque (Downhole)': [None, '-', '-', '↓', '-', '-', '-', '-', '-', '↑', '-',
        '-', '↑', '-', '-', '↑', '↑', '-', '-', '-', '-', '-', '-', '-', '↑', '-',
        '↓', '↑', '-', '-', '↑', '-', '-'],
        'RPM (Downhole)': [None, '-', '-', '↓', '↓', '↓', '-', '-', '-', '↓', '-',
        '-', '-', '-', '-', '↓', '↓', '-', '-', '-', '-', '-', '↓ then ↑,
        repeatedly', '↓ then ↑, repeatedly', '↓', '↑', '↓', '↑', '-', '-', '-', '-',
        '-'],
        'Pressure (Downhole)': [None, '↑', '↑', '↓', '↑', '↑', '-', '↓', '-', '↑',
        '↑', '-', '↑', '↑', '↑', '-', '-', '↑', '-', '-', '-', '-', '-', '-', '-',
        '↓', '-', '↓', '↑', '↑', '↑', '↑', '↑'],
        'Temperature': [None, '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-',
        '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '↑', '-',
        '↑', '-', '-', '-', '-', '-'],
        'ROP': [None, 'uncontrolled', 'uncontrolled', '↓', '↓', '↓', '-', '-', '-',
        '↓', '-', '-', '-', '-', '-', '-', '-', '↑', '-', '-', '-', '-', '-', '↓',
        '↓', '↓', '↓', '↓', '-', '-', '-', '-', '-']}

df = pd.DataFrame(data)
df = df.rename({1: 'Sour Gas Bearing Zones',
                               2: 'Shallow Gas-Bearing Zones',
                               3: 'Stacked Tools',
                               4: 'Resistant Beds Encountered',
                               5: 'Bit Balling',
                               6: 'Formation Cave-in',
                               7: 'Lost Circulation',
                               8: 'Mud Contamination',
                               9: 'Poor Hole Cleaning',
                               10: 'Drilling Fluid Backflow',
                               11: 'Hole Enlargement (Washout)',
                               12: 'Hole Closure (Creep)',
                               13: 'Fracturing',
                               14: 'Collapse and Burst',
                               15: 'Problems Related to Stuckpipe',
                               16: 'Mechanical Pipe Sticking',
                               17: 'Kicks',
                               18: 'Tension Load',
                               19: 'Fatigue',
                               20: 'Heat Check Cracking',
                               21: 'Ductile and Brittle Fractures',
                               22: 'Axial Vibrations',
                               23: 'Torsional Vibrations',
                               24: 'Lateral/transverse Vibrations',
                               25: 'Drillstring Failures',
                               26: 'Drill Bit Jamming',
                               27: 'Twist-off',
                               28: 'Drilling through naturally fractured or faulted
```

```
                                formations',
                                29: 'Drilling through tectonically stressed
                                formations',
                                30: 'Drilling through a mobile formation',
                                31: 'Drilling through a naturally overpressured shale',
                                32: 'Drilling through induced over-pressured shale'})

# Creating the GUI
root = tk.Tk()

root.config(bg="black")

noteStyler = ttk.Style()


# Creating a theme

noteStyler.theme_create('oogboog', settings={
    ".": {
        "configure": {
            "background": 'black', # All except tabs
            "font": 'orange'
        }
    },
    "TNotebook": {
        "configure": {
            "background":'black', # Your margin color
            "tabmargins": [2, 5, 0, 0], # margins: left, top, right, separator
        }
    },
    "TNotebook.Tab": {
        "configure": {
            "background": 'black', # tab color when not selected
            "padding": [39, 11], # [space between text and horizontal tab-button
            border, space between text and vertical tab_button border]
            "font":"blue"
        },
        "map": {
            "background": [("selected", 'black')], # Tab color when selected
            "expand": [("selected", [11, 0, 1, 0])] # text margins
        }
    }
})

noteStyler.theme_use('oogboog')


noteStyler.configure("TNotebook", background='gray36', borderwidth=0,
```

```
highlightbackground='#gray36',tabmargins=0)
noteStyler.configure("TNotebook.Tab", background='gray36', foreground='white',
lightcolor='#gray36', borderwidth=0, font=("Yu Gothic UI Light", 14))
noteStyler.configure("TFrame", background='black', foreground='gray36', borderwidth=0)
noteStyler.configure("Tab", focuscolor=noteStyler.configure(".")["background"])
noteStyler.layout("TNotebook", [])

notebook = ttk.Notebook(root)
notebook.pack(fill=BOTH)

# Creating two tabs
tab1 = tk.Frame(notebook, background="#000000")
tab2 = tk.Frame(notebook, background="#000000")
notebook.add(tab1, text='Drilling Problem Detector')
notebook.add(tab2, text='Anomaly Detector')

# Creating frames
lef_frame = tk.Frame(tab1)
lef_frame.pack(sid="left")
lef_frame.config(bg="black")
ri_frame = tk.Frame(tab1)
ri_frame.pack(sid="right")
ri_frame.config(bg="black")

# Adding image file

bg = PhotoImage(file = "oog.png")

# Creating the Canvas

canvas1 = tk.Canvas(lef_frame, width=657, height=765, borderwidth=0,
highlightthickness=0)
canvas1.grid(row=0, column=0, columnspan=3, rowspan=16, sticky='nsew')

# Displaying image
canvas1.create_image(0, 0, image = bg, anchor = "nw")



bg2 = PhotoImage(file = "boog.png")


# Creating the Canvas
canvas2 = tk.Canvas(ri_frame, width=657, height=764, borderwidth=0,
highlightthickness=0)
canvas2.grid(row=0, column=0, columnspan=3, rowspan=3, sticky='nsew')

# Displaying the image
```

```
canvas2.create_image(0, 0, image = bg2, anchor = "nw")

# Set to full screen mode

root.attributes('-fullscreen',True)

#Setting an icon for the window

root.iconbitmap("icon.ico")

#Creating a title for the window

root.title("Drilling Problem Detector")

#Creating dropwdown menus

options1 = ["","Surface Tank Volume (Pit Volume)", "Return Rate", "SPP (Standpipe
Pressure)", "Flow Rate", "Torque", "RPM", "Hook Load", "Amount of Cuttings", "Mud
density", "Mud viscosity", "Torque (Downhole)", "RPM (Downhole)", "Pressure
(Downhole)", "Temperature", "ROP"]
options2 = ["","↑", "↓", "-", "↑ or ↓ then -", "↓ then ↑, repeatedly", "uncontrolled"]
options3 = ["","Surface Tank Volume (Pit Volume)", "Return Rate", "SPP (Standpipe
Pressure)", "Flow Rate", "Torque", "RPM", "Hook Load", "Amount of Cuttings", "Mud
density", "Mud viscosity", "Torque (Downhole)", "RPM (Downhole)", "Pressure
(Downhole)", "Temperature", "ROP"]
options4 = ["","↑", "↓", "-", "↑ or ↓ then -", "↓ then ↑, repeatedly", "uncontrolled"]
options5 = ["","Surface Tank Volume (Pit Volume)", "Return Rate", "SPP (Standpipe
Pressure)", "Flow Rate", "Torque", "RPM", "Hook Load", "Amount of Cuttings", "Mud
density", "Mud viscosity", "Torque (Downhole)", "RPM (Downhole)", "Pressure
(Downhole)", "Temperature", "ROP"]
options6 = ["","↑", "↓", "-", "↑ or ↓ then -", "↓ then ↑, repeatedly", "uncontrolled"]

var1 = tk.StringVar(lef_frame)
var1.set(options1[0])

var2 = tk.StringVar(tab1)
var2.set(options2[0])

var3 = tk.StringVar(tab1)
var3.set(options3[0])

var4 = tk.StringVar(tab1)
var4.set(options4[0])

var5 = tk.StringVar(tab1)
var5.set(options5[0])

var6 = tk.StringVar(tab1)
```

```
var6.set(options6[0])

tk.Label(lef_frame, text="", bg="black", fg="black", font=("Yu Gothic UI Light", 14),
activebackground="black", activeforeground="black", relief="flat",
highlightthickness=0).grid(row=0, column=2, pady=30)

title1 = tk.Label(lef_frame, text="Indicator #1", font=("Yu Gothic UI Light", 15),
bg="black", fg="white smoke", activebackground="gray34", activeforeground="gray50",
highlightthickness=0, width=30).grid(row=1, column=2)

drop_down1 = tk.OptionMenu(lef_frame, var1, *options1)
drop_down1.config(bg="gray36", fg="white smoke", font=("Yu Gothic UI Light", 11),
activebackground="gray14", activeforeground="gray14", relief="flat",
highlightthickness=0, width=30, indicatoron=0)
drop_down1["menu"].config(bg="gray36", fg="white smoke", font=("Yu Gothic UI Light",
11), activebackground="gray14", activeforeground="gray50", relief="flat")
drop_down1.grid(row=2, column=2)

title2 = tk.Label(lef_frame, text="Change observed:", font=("Yu Gothic UI Light",
15), bg="black", fg="white smoke", activebackground="gray34",
activeforeground="gray50").grid(row=4, column=2, pady=2)

drop_down2 = tk.OptionMenu(lef_frame, var2, *options2)
drop_down2.config(bg="gray36", fg="white smoke", font=("Yu Gothic UI Light", 10),
activebackground="gray14", activeforeground="gray14", relief="flat",
highlightthickness=0, width=22, indicatoron=0)
drop_down2["menu"].config(bg="gray36", fg="white smoke", font=("Yu Gothic UI Light",
10), activebackground="gray14", activeforeground="gray50", relief="flat")
drop_down2.grid(row=5, column=2)

title3 = tk.Label(lef_frame, text="Indicator #2", font=("Yu Gothic UI Light", 15),
bg="black", fg="white smoke", activebackground="gray34",
activeforeground="gray50").grid(row=6, column=2, pady=2)

drop_down3 = tk.OptionMenu(lef_frame, var3, *options3)
drop_down3.config(bg="gray36", fg="white smoke", font=("Yu Gothic UI Light", 11),
activebackground="gray14", activeforeground="gray14", relief="flat",
highlightthickness=0, width=30, indicatoron=0)
drop_down3["menu"].config(bg="gray36", fg="white smoke", font=("Yu Gothic UI Light",
11), activebackground="gray14", activeforeground="gray50", relief="flat")
drop_down3.grid(row=7, column=2, pady=2)

title4 = tk.Label(lef_frame, text="Change observed:", font=("Yu Gothic UI Light",
15), bg="black", fg="white smoke", activebackground="gray34",
activeforeground="gray50").grid(row=8, column=2, pady=2)

drop_down4 = tk.OptionMenu(lef_frame, var4, *options4)
drop_down4.config(bg="gray36", fg="white smoke", font=("Yu Gothic UI Light", 10),
```

```
activebackground="gray14", activeforeground="gray14", relief="flat",
highlightthickness=0, width=22, indicatoron=0)
drop_down4["menu"].config(bg="gray36", fg="white smoke", font=("Yu Gothic UI Light",
10), activebackground="gray14", activeforeground="gray50", relief="flat")
drop_down4.grid(row=9, column=2, pady=2)

title5 = tk.Label(lef_frame, text="Indicator #3", font=("Yu Gothic UI Light", 15),
bg="black", fg="white smoke", activebackground="gray10",
activeforeground="gray50").grid(row=10, column=2, pady=2)

drop_down5 = tk.OptionMenu(lef_frame, var5, *options5)
drop_down5.config(bg="gray36", fg="white smoke", font=("Yu Gothic UI Light", 11),
activebackground="gray14", activeforeground="gray14", relief="flat",
highlightthickness=0, width=30, indicatoron=0)
drop_down5["menu"].config(bg="gray36", fg="white smoke", font=("Yu Gothic UI Light",
11), activebackground="gray14", activeforeground="gray50", relief="flat")
drop_down5.grid(row=11, column=2, pady=2)

title6 = tk.Label(lef_frame, text="Change observed:", font=("Yu Gothic UI Light",
15), bg="black", fg="white smoke", activebackground="gray34",
activeforeground="gray50").grid(row=12, column=2, pady=2)

drop_down6 = tk.OptionMenu(lef_frame, var6, *options6)
drop_down6.config(bg="gray36", fg="white smoke", font=("Yu Gothic UI Light", 10),
activebackground="gray14", activeforeground="gray14", relief="flat",
highlightthickness=0, width=22, indicatoron=0,)
drop_down6["menu"].config(bg="gray36", fg="white smoke", font=("Yu Gothic UI Light",
10), activebackground="gray14", activeforeground="gray50", relief="flat")
drop_down6.grid(row=13, column=2, pady=2)


# Creating a submit function/button
def submit_callback():
    column_name1 = var1.get()
    value1 = var2.get()
    column_name3 = var3.get()
    value3 = var4.get()
    column_name5 = var5.get()
    value5 = var6.get()
    filtered_df = df

    if var1.get() != "" and var2.get() == "":
        messagebox.showwarning("Warning", "The corresponding change must be
        selected.")
    if var3.get() != "" and var4.get() == "":
        messagebox.showwarning("Warning", "The corresponding change must be
        selected.")
    if var5.get() != "" and var6.get() == "":
```

```
        messagebox.showwarning("Warning", "The corresponding change must be
        selected.")
    if var2.get() != "" and var1.get() == "":
        messagebox.showwarning("Warning", "The corresponding indicator must be
        selected.")
    if var4.get() != "" and var3.get() == "":
        messagebox.showwarning("Warning", "The corresponding indicator must be
        selected.")
    if var6.get() != "" and var5.get() == "":
        messagebox.showwarning("Warning", "The corresponding indicator must be
        selected.")
    if column_name1 != '' and value1 != '':
        filtered_df = filtered_df[filtered_df[column_name1] == value1]
    if column_name3 != '' and value3 != '':
        filtered_df = filtered_df[filtered_df[column_name3] == value3]
    if column_name5 != '' and value5 != '':
        filtered_df = filtered_df[filtered_df[column_name5] == value5]
    if column_name1 != '' and column_name3 != '':
        filtered_df = df[(df[column_name1] == value1) & (df[column_name3] == value3)]
    if column_name1 != '' and column_name5 != '':
        filtered_df = df[(df[column_name1] == value1) & (df[column_name5] == value5)]
    if column_name5 != '' and column_name3 != '':
        filtered_df = df[(df[column_name5] == value5) & (df[column_name3] == value3)]

    if filtered_df.empty:
        print("No results found.")
        result_label.config(text="No results found.", fg="white smoke")
    elif len(filtered_df) > 1:
        print("More than one match found:", filtered_df.index.tolist())
        result_label.config(result_label.config(text="More than one problem was
        found:\n" + "\n".join(filtered_df.index.tolist()), fg="white smoke", wraplength=51
    else:
        row_value = filtered_df.index[0]
        print("The drilling problem is:", row_value)
        result_label.config(text=f"The drilling problem is {row_value}", fg="white
        smoke")

submit_button = tk.Button(lef_frame, text="Submit", command=submit_callback,
bg="gray36", fg="white smoke", font=("Yu Gothic UI Light", 14),
activebackground="gray34", activeforeground="gray50", relief="flat",
highlightthickness=0, takefocus=FALSE)
submit_button.grid(row=14, column=2, pady=13)


# Creating a quit function/button

def quit_program():
    root.destroy()
```

```
quit_button = tk.Button(lef_frame, text="Quit", command=quit_program, bg="gray36",
fg="white smoke", font=("Yu Gothic UI Light", 14), activebackground="gray34",
activeforeground="gray50", relief="flat", highlightthickness=0, takefocus=FALSE)
quit_button.grid(row=15, column=2, padx=233)


tk.Label(lef_frame, text="Copyright ©2023 Salar Hafezi. All rights reserved.",
bg="gray9", fg="white smoke", font=("Yu Gothic UI Light", 9),
activebackground="gray34", activeforeground="gray50", relief="flat",
highlightthickness=0).grid(row=16, column=0)
tk.Label(lef_frame, text="", bg="black", fg="black", font=("Yu Gothic UI Light", 14),
activebackground="black", activeforeground="black", relief="flat",
highlightthickness=0).grid(row=15, column=1, pady=40)
tk.Label(lef_frame, text="", bg="black", fg="black", font=("Yu Gothic UI Light", 14),
activebackground="black", activeforeground="black", relief="flat",
highlightthickness=0).grid(row=15, column=1, padx=29)


tk.Label(ri_frame, text="", bg="black", fg="black", font=("Yu Gothic UI Light", 14),
activebackground="black", activeforeground="black", relief="flat",
highlightthickness=0).grid(row=15, column=2, padx=160)


tk.Label(ri_frame, text="", bg="black", fg="black", font=("Yu Gothic UI Light", 14),
activebackground="black", activeforeground="black", relief="flat",
highlightthickness=0).grid(row=0, column=0, pady=10)

# Display the filtered

result_label = Label(ri_frame, text="", width=50, height=33, font=("Yu Gothic UI Light", 1

result_label.grid(row=1, column=0, pady=2)







# Anomaly Detector/Tab2

# Initializing data of lists
data2 = {'Surface Tank Volume (Pit Volume)': [None, '↑', '↑', '↓', '-', '-', '-',
'↓', '-', '↑', '↑', '-', '-', '↓', '↑', '-', '-', '↑', '-', '-', '-', '-', '-', '-',
'-', '↓', '-', '↓', '↑', '↑', '-', '↑', '↑'],
        'Return Rate': [None, '↑', '↑', '↓', '-', '-', '↓', '↓', '-', '↑', '↑', '-',
```

```
    '-', '↓', '↑', '-', '-', '↑', '-', '-', '-', '-', '-', '-', '-', '↓', '-',
    '↓', '↑', '↑', '-', '↑', '↑'],
    'SPP (Standpipe Pressure)': [None, '↑', '↑', '↓', '↑', '↑', '-', '↓', '-',
    '↑', '↑', '-', '↑', '↑', '↑', '-', '↑', '↑', '-', '-', '-', '-', '-', '-',
    '-', '↓', '-', '↓', '↑', '↑', '↑', '↑', '↑'],
    'Flow Rate': [None, '↓', '↓', '↑', '-', '-', '↓', '↑', '-', '↓', '↓', '-',
    '-', '↑', '↓', '-', '-', '↓', '↑ or ↓ then -', '↑ or ↓ then -', '↑ or ↓ then
    -', '↑ or ↓ then -', '-', '-', '-', '↑', '-', '↑', '↓', '↓', '-', '↓', '↓'],
    'Torque': [None, '-', '-', '-', '-', '-', '-', '-', '-', '↑', '-', '-', '↑',
    '-', '↑', '↑', '↑', '-', '-', '-', '-', '-', '-', '-', '↑', '-', '-', '↑',
    '↑', '↑', '↑', '↑', '↑', ],
    'RPM': [None, '-', '-', '-', '↓', '↓', '-', '-', '-', '↓', '-', '-', '-',
    '-', '-', '↓', '↓', '-', '-', '-', '-', '-', '↓ then ↑, repeatedly', '↓',
    '↓', '↑', '↓', '↑', '-', '-', '-', '-', '-', ],
    'Hook Load': [None, '-', '-', '↓', '-', '↑', '-', '-', '-', '-', '-', '-',
    '-', '-', '-', '-', '-', '↓', '-', '-', '-', '-', '-', '-', '-', '-', '-',
    '-', '-', '-', '-', '-', '-'],
    'Amount of Cuttings': [None, '-', '-', '-', '-', '-', '↑', '-', '-', '-',
    '-', '↓', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-',
    '-', '-', '-', '-', '-', '-', '-', '-'],
    'Mud density': [None, '-', '-', '-', '-', '-', '-', '-', '↑', '-', '-', '-',
    '-', '-', '-', '-', '-', '↓', '-', '-', '-', '-', '-', '-', '-', '-', '-',
    '-', '-', '-', '-', '-', '-'],
    'Mud viscosity': [None, '-', '-', '-', '-', '-', '-', '-', '↑', '-', '-',
    '-', '-', '-', '-', '-', '-', '↓', '-', '-', '-', '-', '-', '-', '-', '-',
    '-', '-', '-', '-', '-', '-', '-'],
    'Torque (Downhole)': [None, '-', '-', '↓', '-', '-', '-', '-', '-', '↑', '-',
    '-', '↑', '-', '-', '↑', '↑', '-', '-', '-', '-', '-', '-', '-', '↑', '-',
    '↓', '↑', '-', '-', '↑', '-', '-'],
    'RPM (Downhole)': [None, '-', '-', '↓', '↓', '↓', '-', '-', '-', '↓', '-',
    '-', '-', '-', '-', '↓', '↓', '-', '-', '-', '-', '-', '↓ then ↑,
    repeatedly', '↓ then ↑, repeatedly', '↓', '↑', '↓', '↑', '-', '-', '-', '-',
    '-'],
    'Pressure (Downhole)': [None, '↑', '↑', '↓', '↑', '↑', '-', '↓', '-', '↑',
    '↑', '-', '↑', '↑', '↑', '-', '-', '↑', '-', '-', '-', '-', '-', '-', '-',
    '↓', '-', '↓', '↑', '↑', '↑', '↑', '↑'],
    'Temperature': [None, '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-',
    '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '↑', '-',
    '↑', '-', '-', '-', '-', '-'],
    'ROP': [None, 'uncontrolled', 'uncontrolled', '↓', '↓', '↓', '-', '-', '-',
    '↓', '-', '-', '-', '-', '-', '-', '-', '↑', '-', '-', '-', '-', '-', '↓',
    '↓', '↓', '↓', '↓', '-', '-', '-', '-', '-']}

df2 = pd.DataFrame(data)
df2 = df2.rename({1: 'Sour Gas Bearing Zones',
                2: 'Shallow Gas-Bearing Zones',
                3: 'Stacked Tools',
                4: 'Resistant Beds Encountered',
```

```
                                 5: 'Bit Balling',
                                 6: 'Formation Cave-in',
                                 7: 'Lost Circulation',
                                 8: 'Mud Contamination',
                                 9: 'Poor Hole Cleaning',
                                 10: 'Drilling Fluid Backflow',
                                 11: 'Hole Enlargement (Washout)',
                                 12: 'Hole Closure (Creep)',
                                 13: 'Fracturing',
                                 14: 'Collapse and Burst',
                                 15: 'Problems Related to Stuckpipe',
                                 16: 'Mechanical Pipe Sticking',
                                 17: 'Kicks',
                                 18: 'Tension Load',
                                 19: 'Fatigue',
                                 20: 'Heat Check Cracking',
                                 21: 'Ductile and Brittle Fractures',
                                 22: 'Axial Vibrations',
                                 23: 'Torsional Vibrations',
                                 24: 'Lateral/transverse Vibrations',
                                 25: 'Drillstring Failures',
                                 26: 'Drill Bit Jamming',
                                 27: 'Twist-off',
                                 28: 'Drilling through naturally fractured or faulted
                                 formations',
                                 29: 'Drilling through tectonically stressed
                                 formations',
                                 30: 'Drilling through a mobile formation',
                                 31: 'Drilling through a naturally overpressured shale',
                                 32: 'Drilling through induced over-pressured shale'})



options7 = ['','Sour Gas Bearing Zones','Shallow Gas-Bearing Zones','Stacked
Tools','Resistant Beds Encountered','Bit Balling','Formation Cave-in','Lost
Circulation','Mud Contamination','Poor Hole Cleaning','Drilling Fluid Backflow','Hole
Enlargement (Washout)','Hole Closure (Creep)','Fracturing','Collapse and
Burst','Problems Related to Stuckpipe','Mechanical Pipe Sticking','Kicks','Tension
Load','Fatigue','Heat Check Cracking','Ductile and Brittle Fractures','Axial
Vibrations','Torsional Vibrations','Lateral/transverse Vibrations','Drillstring
Failures','Drill Bit Jamming','Twist-off','Drilling through naturally fractured or
faulted formations','Drilling through tectonically stressed formations','Drilling
through a mobile formation','Drilling through a naturally overpressured
shale','Drilling through induced over-pressured shale']

#Creating frames
```

```
lef_frame2 = tk.Frame(tab2)
lef_frame2.pack(sid="left")
lef_frame2.config(bg="black")
ri_frame2 = tk.Frame(tab2)
ri_frame2.pack(sid="right")
ri_frame2.config(bg="black")

bg3 = PhotoImage(file = "oog.png")

# Create Canvas

canvas3 = tk.Canvas(lef_frame2, width=657, height=764, borderwidth=0,
highlightthickness=0)
canvas3.grid(row=0, column=0, columnspan=3, rowspan=16, sticky='nsew')

# Display image
canvas3.create_image(0, 0, image = bg3, anchor = "nw")



bg4 = PhotoImage(file = "boog.png")


# Create Canvas
canvas4 = tk.Canvas(ri_frame2, width=657, height=764, borderwidth=0,
highlightthickness=0)
canvas4.grid(row=0, column=0, columnspan=3, rowspan=3, sticky='nsew')

# Display image
canvas4.create_image(0, 0, image = bg4, anchor = "nw")

var7 = tk.StringVar(lef_frame2)
var7.set(options7[0])


tk.Label(lef_frame2, text="", bg="black", fg="black", font=("Yu Gothic UI Light",
14), activebackground="black", activeforeground="black", relief="flat",
highlightthickness=0).grid(row=0, column=2, pady=130)

title7 = tk.Label(lef_frame2, text="Drilling Problem:", font=("Yu Gothic UI Light",
15), bg="black", fg="white smoke", activebackground="gray34",
activeforeground="gray50", highlightthickness=0, width=30).grid(row=1, column=2,
pady=2)


drop_down7 = ttk.Combobox(lef_frame2, textvariable=var7)
drop_down7.config(background="gray36", foreground="white smoke", font=("Yu Gothic UI
Light", 14), width=47)
```

```
drop_down7['values'] = options7
drop_down7['state'] = 'readonly'




# The following alters the Listbox
root.option_add('*TCombobox*Listbox*Background', "gray36")
root.option_add('*TCombobox*Listbox*Foreground', "white smoke")
root.option_add('*TCombobox*Listbox*selectBackground', "gray14")
root.option_add('*TCombobox*Listbox*selectForeground', "gray50")
root.option_add('*TCombobox*Listbox.font', ("Yu Gothic UI Light", 14))
root.option_add('*TCombobox*Listbox.highlightthickness', 0)
root.option_add('*TCombobox*Listbox.bordercolor', 'gray36')
root.option_add('*TCombobox*Listbox*relief', "flat")


# The following alters the Combobox entry field
noteStyler.map('TCombobox', fieldbackground=[('readonly', "gray36")])
noteStyler.map('TCombobox', selectbackground=[('readonly', "gray36")])
noteStyler.map('TCombobox', selectforeground=[('readonly', "white smoke")])
noteStyler.map('TCombobox', font=[('readonly', ("Yu Gothic UI Light", 14))])
noteStyler.map('TCombobox', highlightthickness=[('readonly', 0)])
noteStyler.map('TCombobox', background=[('readonly', "gray36")])
noteStyler.map('TCombobox', bordercolor=[('readonly', "gray36")])
noteStyler.map('Vertical.TScrollbar',
          background=[('active', 'gray14'), ('!active', 'gray36')],
          bordercolor=[('active', 'gray36'), ('!active', 'gray36')],
          highlightthickness=[('active', 0), ('!active', 0)],
          troughcolor=[('active', 'gray14'), ('!active', 'gray14')])

drop_down7.grid(row=2, column=2, pady=2, padx=12)


def submit_callback2():
    row_index = var7.get()
    row_data = df2.loc[row_index]
    result_label2.config(text=f'Surface Tank Volume (Pit Volume): {row_data["Surface
    Tank Volume (Pit Volume)"]}\nReturn Rate: {row_data["Return Rate"]}\nSPP
    (Standpipe Pressure): {row_data["SPP (Standpipe Pressure)"]}\nFlow Rate:
    {row_data["Flow Rate"]}\nTorque: {row_data["Torque"]}\nRPM:
    {row_data["RPM"]}\nHook Load: {row_data["Hook Load"]}\nAmount of Cuttings:
    {row_data["Amount of Cuttings"]}\nMud density: {row_data["Mud density"]}\nMud
    viscosity: {row_data["Mud viscosity"]}\nTorque (Downhole): {row_data["Torque
    (Downhole)"]}\nRPM (Downhole): {row_data["RPM (Downhole)"]}\nPressure (Downhole):
    {row_data["Pressure (Downhole)"]}\nTemperature: {row_data["Temperature"]}\nROP:
    {row_data["ROP"]}', fg="white smoke", wraplength=510, justify=LEFT)
```

```
submit_button = tk.Button(lef_frame2, text="Submit", command=submit_callback2,
bg="gray36", fg="white smoke", font=("Yu Gothic UI Light", 14),
activebackground="gray34", activeforeground="gray50", relief="flat",
highlightthickness=0, takefocus=FALSE)
submit_button.grid(row=13, column=2, pady=13)


# Display the filtered

def quit_program():
    root.destroy()

quit_button2 = tk.Button(lef_frame2, text="Quit", command=quit_program, bg="gray36",
fg="white smoke", font=("Yu Gothic UI Light", 14), activebackground="gray34",
activeforeground="gray50", relief="flat", highlightthickness=0, takefocus=FALSE)
quit_button2.grid(row=14, column=2, pady=2)

tk.Label(lef_frame2, text="", bg="black", fg="black", font=("Yu Gothic UI Light", 9),
activebackground="black", activeforeground="black", relief="flat",
highlightthickness=0).grid(row=15, column=0, pady=134)
tk.Label(lef_frame2, text="Copyright ©2023 Salar Hafezi. All rights reserved.",
bg="gray9", fg="white smoke", font=("Yu Gothic UI Light", 9),
activebackground="gray34", activeforeground="gray50", relief="flat",
highlightthickness=0).grid(row=16, column=0)
tk.Label(lef_frame2, text="", bg="black", fg="black", font=("Yu Gothic UI Light",
14), activebackground="black", activeforeground="black", relief="flat",
highlightthickness=0).grid(row=15, column=1, pady=40)
tk.Label(lef_frame2, text="", bg="black", fg="black", font=("Yu Gothic UI Light",
14), activebackground="black", activeforeground="black", relief="flat",
highlightthickness=0).grid(row=15, column=1, padx=29)


tk.Label(ri_frame2, text="", bg="black", fg="black", font=("Yu Gothic UI Light", 14),
activebackground="black", activeforeground="black", relief="flat",
highlightthickness=0).grid(row=15, column=1, padx=160)

tk.Label(ri_frame2, text="", bg="black", fg="black", font=("Yu Gothic UI Light", 14),
activebackground="black", activeforeground="black", relief="flat",
highlightthickness=0).grid(row=0, column=0, pady=10)

result_label2 = Label(ri_frame2, text="", width=50, height=33, font=("Yu Gothic UI
Light", 11),bg= "gray36", relief="flat", highlightthickness=0)

result_label2.grid(row=1, column=0, pady=2)

root.mainloop()
```

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