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MASTER'S THESIS

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Writer: Mamdouh Dahham (Writer's signature)
Faculty supervisor: Jan Einar Gravdal	
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Abstract

The last ten years have witnessed a growing interest in the evolution of technology and autonomous systems in drilling operations after the oil and gas companies realized that the next stage in the exploration and production of oil gas is to drill more wells, often characterized by narrow pressure margins. The drilling challenges in narrow margin pressure wells such as depleted reservoirs, deep water, extended-reach wells (ERD) and High Pressure High Temperature (HPHT) wells require more accuracy and high sensitivity in drilling operations. These wells are more susceptible to drilling incidents such as formation influx, lost circulation, and pack-off, leading to increased non-productive time (NPT) and increased costs.

The introduction of the automation process in drilling systems based on automated tools during drilling operations such as wired drill pipe (WDP) and along-string measurements (ASM) was required to reduce the NPT, thus reducing the drilling costs and keeping the humans away from the hazardous area. Additionally, an automated system is intended to optimize the drilling operations by monitoring, modelling and controlling the acquisition data, which are real physical measurements transmitted from the well downhole.

The Managed Pressure Drilling (MPD) methodology with different variants and techniques is seen to be a promising solution during drilling operations in narrow pressure margin wells compared to conventional drilling methods. By utilizing automated back-pressure control, together with more accurate flow meter, such as the Coriolis flow meter, it is possible to react rapidly to any unindented influx and to compensate for pressure variations during circulation and connection.

Drilling fluid properties and rheology play an essential role during drilling operations. Choosing the proper mud density, viscosity, and rheology is a key to maintaining equivalent circulating density (ECD) between formation pore pressure gradient and fracture pressure gradient, thus avoid drilling problems such as formation influx, lost circulation and stuck pipe.

In this thesis, the OpenLab drilling simulator provides synthetic measurements that are used to create a workflow algorithm that selects the optimum set-points for MPD back-pressure and drilling fluid properties. Optimization of the MPD method and selecting proper drilling fluid properties during drilling help to maintain the bottom-hole pressure (BHP) and prevent lost circulation, kick occurring and other drilling incidents and thus maintain the wellbore in safe mode.

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Student:

Mandouh Dahham

Date:

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Contents

Nomenclature	x
0.1 Abbreviations	x
1 Introduction	1
1.1 Objective	1
1.2 Background	1
1.3 Thesis Question	1
1.4 Scope of work	2
1.5 The motivation for this master study	2
1.6 Structure of thesis	3
2 Automation	5
2.1 Introduction	5
2.1.1 What is Automation?	5
2.1.2 Automation applications	5
2.2 Automation properties	5
2.2.1 Advantages of Automation	5
2.2.2 Disadvantage of Automation	6
2.3 How does Automation work?	6
2.3.1 Automation elements	6
2.3.2 Monitoring	6
2.3.3 Modeling	8
2.3.4 Controlling	8
2.4 Control System	9
2.4.1 Classification of Control Systems	9
2.4.2 Control Algorithm	9
2.4.3 PID Controller	11
2.4.4 Simulations	14
3 Drilling Automation Tools	16
3.1 Introduction	16
3.1.1 Drilling Automation	16
3.1.2 Drilling automation system review	18
3.2 Drilling automation tools	21
3.2.1 Wired Drill Pipe (WDP)	21
3.2.2 Along string measurement (ASM)	23

4	Drilling Fluid Properties	27
4.1	Introduction	27
4.2	Rheology	27
4.3	Drilling fluid properties	29
4.3.1	Viscosity	29
4.3.2	Gel strength	30
4.3.3	Control Filtration	31
4.3.4	Density	32
4.4	Drilling fluid properties and rheology impact	33
4.4.1	Bottomhole Pressure (BHP)	33
4.4.2	Equivalent Circulating Density (ECD)	35
4.4.3	Cuttings transport	36
5	Narrow Pressure Margin Wells	43
5.1	Narrow Pressure Margin Well	43
5.2	Potential Incidents in Narrow pressure margin well	44
5.2.1	Formations Influx	44
5.2.2	Lost circulation	45
5.2.3	Pack off	47
5.3	Managing the narrow pressure margin wells	48
6	Managed Pressure Drilling (MPD)	51
6.1	Introduction	51
6.1.1	Definition of MPD	52
6.1.2	The basic techniques and applications of MPD	52
6.1.3	MPD Equipment System	53
6.2	MPD, UBD and OBD methods	54
6.2.1	Managed Pressure Drilling and Under Balanced Drilling	55
6.2.2	Managed Pressure Drilling and Over Balanced Drilling	56
6.3	Managed Drilling Pressure advantages	60
6.4	Managed Drilling Pressure disadvantages	62
6.5	Summary	62
7	Simulation Case Study	63
8	Results and Conclusion	84
8.1	Introduction	84
8.2	Block Diagram of cases	84
8.2.1	Configuration of case study	84
8.2.2	Drilling process requirements	85
8.2.3	Influx and lost circulation incidents	86
8.2.4	Optimization MPD and Drilling fluid properties	88
8.3	Conclusion	94
A	Appendix	95
A.1	Case Description	95
A.1.1	Configuration of Study Case	95
A.2	Matlab Coding	105
A.2.1	FlowSweep_BHPCControl_Coding	105

A.2.2	Drilling	107
A.2.3	Influx/ Loss based on Geopressure	109
A.2.4	Manual Influx	111
A.3	SI Metric Conversion Factors	112
A.4	Sequences of setpoints in different cases	113

List of Figures

2.1	Data acquisition system https://en.wikipedia.org/wiki/File:DigitalDAQv2.pdf	7
2.2	Driller chair [https://www.nov.com/products/drilling-control-systems-and-rig-automation/contactus]	8
2.3	Open Loop Control Systems	10
2.4	Closed Loop Control System	11
2.5	The control system terminology	12
2.6	P, PI and PID controller	13
2.7	PID structure https://maldu512.medium.com/pid-control-explained-45b671f10bc7	14
3.1	Halliburton's automated rig	17
3.2	Automated Well Construction System https://www.aogr.com/magazine/cover-story/automation-of-downhole-surface-components-optimizes-drilling-process	18
3.3	Integrated Drilling Automation System	19
3.4	DWOB controller system diagram	20
3.5	Downhole Broadband Solution https://www.nov.com/products/downhole-broadband-solutions	22
3.6	NOVOS SYSTEM EFFICIENCY	23
3.7	overview of the IntelliServ network including the BlackStream ASM https://www.hartenergy.com/exclusives/highway-downhole-data-delivers-optimized-drilling-176314	25
3.8	ASMs Kick and FlowChart	26
3.9	Along String Measurements ASM	26
4.1	Rheology Models	28
4.2	Flow Regimes	29
4.3	Different viscometers	30
4.4	Drilling fluid filtration process and filtration test	31
4.5	Measuring Mud density methods	33
4.6	ECD in safe window	36
4.7	Effect of Flow Rate (RPM) on cutting transport	38
4.8	Effect of mud PV/YS ratio of drilling fluids on Carrying Capacity	39
4.9	Effect of combined effects (RPM) and rheological properties on cutting transport	40
4.10	Mud density effect on cutting transport	41
5.1	DeepWater and Shallow wells with operating margin and fracture gradient	44

5.2	kick and lost circulation ((www.drilling-mud.org)	46
5.3	Pack off incident(www.drillingcourse.com)	48
5.4	Downhole Pressures(https://www.beyondenergy.ca/mpd-101/)	49
5.5	Drilling Window (https://www.beyondenergy.ca/mpd-101/)	50
6.1	MPD application zones	52
6.2	MPD System components [https://www.beyondenergy.ca/mpd/]	53
6.3	MPD System Diagram [Weatherford,2015]	54
6.4	Pressure profile window(JPT.org)	55
6.5	Difference between MPD and Conventional Drilling	57
6.6	BHP in MPD and Conventional drilling method (Sciencedirect.com)	58
6.7	The usage of Back Pressure in CBHP Method	59
6.8	Bottom hole pressure tracking during pipe connection sequence	60
6.9	NPT in the Gulf of Mexico [60]	61
7.1	Configuration of Case Study	64
7.2	OpenLab Simulation	65
7.3	Hole Section	66
7.4	Geopressures	67
7.5	Fluid Properties	68
7.6	Drill string includes BHA, Bit and Drillpipe components	69
7.7	Drilling with no influx or loss display	71
7.8	Setpoints for drilling operation with no influx or loss	72
7.9	Influx mass and Pit volume	74
7.10	The moment the kick is occurred	74
7.11	Influx and circulating the kick out of the well	75
7.12	Monitored Mud loss example	76
7.13	Example with loss and influx	77
7.14	FlowSweep and BHP control from matlab	78
7.15	Drilling operation from Matlab	80
7.16	Influx/Loss Based on Geopressure from Matlab	81
7.17	Manual Influx and Loss Example A	82
7.18	Manual Influx and Loss Example B	83
8.1	OpenLab configuration	85
8.2	Drilling process requirements	86
8.3	influx incident detection	87
8.4	Lost circulation detection	88
8.5	ECD control	89
8.6	Work-flow algorithm when using the OpenLab simulator to find optimum MPD settings and mud properties for a planned drilling operation	92
8.7	Work-flow algorithm of real drilling operation for narrow pressure margin wells, using the OpenLab simulator to assist in the choice of drilling parameters	93

List of Tables

2.1	Comparasion Of Gain Response Of P, Pi And Pid Controllers	12
2.2	P Controller, PI Controller and PID Controller effect	13
4.1	Factors that effect hole cleaning performance	37
6.1	Objectives of MPD techniques	53
6.2	MPD vs Conventional method in well control	60
7.1	Setpoints to simulate from Matlab (Manual Influx/Loss)	82
A.1	Rig components	95
A.2	Formation strength	96
A.3	Air	96
A.4	Water	96
A.5	Solid	96
A.6	Geopressures	97
A.7	Drill Pipe	98
A.8	Bottom hole assembly	98
A.9	Bit	98
A.10	Rheology	98
A.11	Base-oil-pvt (s.g.)	99
A.12	Caption	99
A.13	Survey stations-1	100
A.14	Survey stations-2	101
A.15	Survey stations-3	102
A.16	Survey stations-4	103
A.17	Survey stations-5	104
A.18	Survey stations-6	104
A.19	Riser	105
A.20	Casings	105
A.21	Open hole	105

Nomenclature

0.1 Abbreviations

- MPD Managed Pressure Drilling
- HMI Human Machine Interface
- ROP Rate Of Penetration
- PID Proportional Integral Derivative
- NPT Non-Productive Time
- RSS Rotary-Steerable System
- CLDA Closed-Loop Downhole Automation
- PAS Process Automation System
- ASM Along String Measurement
- WDP Wired Drill Pipe
- IOR Increased Oil Recovery
- BHA Bottom Hole Assembly
- HPHT High Pressure High Temperature
- ECD Equivalent Circulating Densities
- NORCE Norwegian Research Centre .
- TVD True Vertical Depth
- MD Measured Depth
- WOB Weight On Bit
- BOP Blow Out Preventer
- YP yield point
- PV Plastic Viscosity
- CMC Sodium Carboxymethylcellulose

- OBM Oil-Based-Mud
- WBM Water-Based-Mud
- BHA Bottomhole Assembly
- LOT LeakOff Test
- FIT Formation Integrity Test
- IADC International Association of Drilling Contractors
- RCD rotating circulating device
- UBD Under Balanced Drilling
- OBD Over Balanced Drilling
- AFP Annular Frictional Pressure

Chapter 1

Introduction

1.1 Objective

This thesis aims to create a workflow algorithm that optimizes the drilling operation with respect to the length of the section and ensures a safe and efficient operation within the operational bounds. The workflow algorithm represents a basis that can make use of other algorithms to ensure safe and efficient drilling operations.

1.2 Background

One of the most efficient means to increase oil recovery from existing oil gas fields is to drill more wells. Hence, Increased Oil Recovery (IOR) may involve drilling in depleted reservoirs. IOR drilling operations are sometimes associated with uncertain pressure windows. It is crucial to reach the production zone with minimum energy and time, i.e. with few casings and avoiding drilling hazards (e.g. kick, lost circulation, pack-off, stuck pipe). Drilling process optimization is also crucial for geothermal drilling, where drilling is the cost driver, and it is crucial to drill with less energy consumption and avoid drilling hazards.

Back-pressure Managed Pressure Drilling (MPD) is a method to control the pressure precisely and actively. Back-pressure MPD is especially efficient when drilling in depleted reservoirs and narrow pressure margin sections because of rapidly changing the well pressure.

Wired drill pipe telemetry enables distributed pressure measurements along the drillstring and transmission of these measurements to the surface in real-time. The ability to monitor and control the wellbore pressure profile is therefore improved.

1.3 Thesis Question

Is it possible to find an optimization algorithm that ensures optimum set points for:

- (1) MPD backpressure,
- (2) Drilling fluid density and
- (3) Drilling fluid viscosity,

to prevent drilling problems throughout the entire section and possibly to elongate the section? I.e. how can we find the optimum parameters that don't exceed any bounds w.r.t geopressure and sufficient cuttings transport, and with optimum Rate of Penetration (ROP)?

1.4 Scope of work

In this thesis, work procedures to find the optimal set-points are based on simulations in the OpenLab simulator, together with Matlab and Python programs. The scope of work has been as follows:

- Selecting a geopressure profile and different strategies that enable drilling the entire section.
- Selecting the constraints during the drilling, such as geopressure profiles, drilling speed(cuttings transport) and limitations in equipment and drilling fluid system.
- Performing the simulation in Openlab after making a proper configuration.
- Investigating MPD and drilling fluid properties effect.
- Creating an algorithm that automatically selects the optimum set-points during drilling.

1.5 The motivation for this master study

In the future, oil and gas companies will to a larger extend drill more challenging wells, such as in deep water, mature fields, or long extended reach tie-back wells. These are often characterized by a narrow pressure margin. Deepwater wells, Extended reach wells (ERD), High-pressure High-temperature (Formation Temperature > 150 °C and Wellhead Pressure > 690 bar) and Depleted reservoirs wells represent narrow geopressure margins and significant challenges in the drilling process that require more accuracy in drilling operations.

Drilling incidents such as formation influx, lost circulation, pack off and other challenges in drilling operation result in high costs due to increasing Non-productive time (NPT), reduction of human safety and increasing the risk of environmental pollution.

BHP is one of the most critical measurements that has to be focused on during drilling operations. In the last two decades, the oil and gas companies intend to innovate and develop drilling methods to adjust the downhole pressure. New methodologies has been investigated, such as UBD and MPD to adjust the bottomhole pressure. These methods can help to prevent drilling accidents, thus reducing NPT and reducing the hazards that can occur to humans and the environment.

By optimization of drilling fluid properties and MPD configuration, better control of BHP and ECD in the wellbore can be obtained and drilling problems can be avoided. As a result, longer sections can be drilled when constantly monitoring the in-situ well conditions, and when adjusting fluid properties and MPD setting accordingly.

The choice of drilling fluid properties and MPD settings have been important means in drilling to control the downhole pressure and reach the target with the lowest possible cost. Different automation systems have been applied with different emphasis on automatic choke control, flow meters for detection of kick or lost circulation, and MPD techniques such as Pressurized Mud Cap Drilling (PMCD), Dual Gradient Drilling (DGD) and Constant Bottom Hole Pressure control (CBHP).

Today's application of MPD methods and drilling fluid properties are needed to handle any reservoir response, and to keep the well properly controlled, and is seen as the best practice to control the annular pressure in the wellbore mitigate drilling incidents. In 2007 Equinor started to use the back-pressure MPD method to control the downhole pressure and to prevent lost circulation problems. For instance, in the Gullfaks field by Statoil and Halliburton operator [73] [34], Two wells Kvitebjørn (Syltøy (2008) and Godhavn (2009), which is characterized as depleted HPHT field with narrow pressure margin.

Skarv/Idun field is an example of floating application of Managed Pressure Drilling (MPD) which has been used on Norwegian Continental Shelf offshore is as a solution to control the pressure and mitigate environmental impact using RCD technologies by reducing annual CO₂ emissions by 22,000 tonnes and cost by NOK 19 million [12][30][34]

The telemetry innovations, depending on automation system and the development of processing methods in a drilling system, aim to reduce the costs of the drilling operation and secure a safe environment for human and climate, which are the main goals for the oil and gas industry in the future.

1.6 Structure of thesis

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

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

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

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

The fourth chapter includes drilling fluid descriptions, Rheology and properties.

The fifth chapter includes the description of Narrow Pressure Margin wells and the drilling challenges.

In the sixth chapter, the MPD methodology has been explained. It consists of

the basic variants and techniques of MPD, the comparison between Conventional methods, MPD and UBD, advantages and disadvantages of using the MPD method.

The seventh chapter describes the work implements to obtain the optimization of MPD and drilling fluid properties.

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

Chapter 2

Automation

2.1 Introduction

2.1.1 What is Automation?

Automation is a relatively new term given to everything that works independently without human intervention, so any automated industry can be called industrial automation, for instance. Evolving from manual operations to automation is a process that aims to make laboratories and workshops more dependent on machines instead of humans, often with the objective to improve security, safety and efficiency. In practice, it can involve robots but often controlled by humans. Automation aims to increase production as the machine can work faster and more accurately than humans and hundreds of times less time[53].

The term automation has many definitions. The most comprehensive definition to describe automation is 'the application of technologies, programs, digitization, robotics or processes to achieve outcomes with minimal human input'. [70].

2.1.2 Automation applications

Automation has been widespread recently in many areas such as space, home applications, hospitals, electrical power generation, and distribution. It is being used widely in industry, for instance, chemical industries and oil industries.

2.2 Automation properties

2.2.1 Advantages of Automation

A relevant question is: Why automation?.

The advantages attributed to automation include:

- The performance efficiency.
- Increasing productivity and production rates as the duration of the manufacturing cycle are reduced by removing non-productive time in the manufacturing process.
- Typical performance of automation compared with workmanship by humans leads to a better quality of the product in the manufacturing process.
- Worker safety since automation is being used without or with less human interventions, leading to fewer hazards than can force humans[68].

2.2.2 Disadvantage of Automation

The disadvantages of automation can be limited to.

-The high capital expenses requires a significant investment in equipment that requires a long period of intensive use to recover the invested money.

-Lack of manufacturing flexibility, as production designs are frozen for long periods. This lack of flexibility in manufacturing may be dangerous in an industry where change is rapid or unpredictable.

Tool maintenance and replacement costs tend to rise because all tools must be disassembled simultaneously for specific purposes at regular intervals, whether these tools need it or not.[69]

2.3 How does Automation work?

2.3.1 Automation elements

Monitoring, Modeling and controlling are automation elements attributed to the automation system and illustrated the process of the autonomous system by monitoring what is happening to the system, predicting what will happen and regulating the mechanism and demeanour of the system.[69]

2.3.2 Monitoring

There are many requirements and data to monitor what is happening to the system.

- Data Analysis: Using the computer to discover beneficial information by filtering, transforming and modelling.

- Data Acquisition: Many components involve the process of measuring the real-world physical parameters and converting the measured signals into digital numeric values to be manipulated by a computer. These components are:

- Sensor or transmitter used to measure real-world physical parameters and convert those physical measurements to electrical signals.
- Signal conditioning circuitry, converts electrical sensor signals to get filtered and amplified signals into a form that A/D converters can digitize.
- Analog-to-digital converters (A/D Converters) used to convert the electrical conditioned sensor signals to digital values can be manipulated by a computer.
- Programmable Logic Controller (PLC) is a small computer with a specialized and optimized operating system to handle incoming events in real-time. PLC has input lines connected to sensors to notify the incoming events and output lines connected to actuators to apply the signal reaction to the incoming events. See 2.1

Digital Data Acquisition System

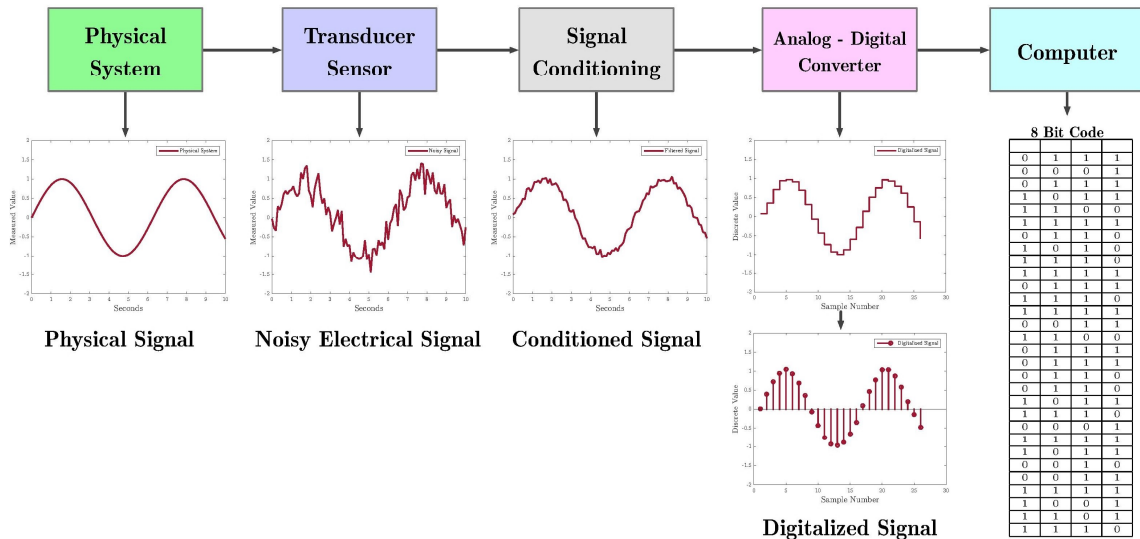


Figure 2.1: Data acquisition system
<https://en.wikipedia.org/wiki/File:DigitalDAQv2.pdf>

Figure (2.1) illustrates the process of converting physical signals to digital signals through the Acquisition System.

- Data quality control: Measured data should be controlled to have a high quality of data by subjecting the raw data to different types of filters and removing the noises to obtain the required data.
- Visualizing of data: It can be obtained using Human Machine Interface (HMI) see figure. HMI is a software application that displays the information in a graphic format that allows operators to know the state of the process. The operators use the monitored graphical information to accept and implement the control instructions, such as the Drillers chair used for data visualization. see 2.2

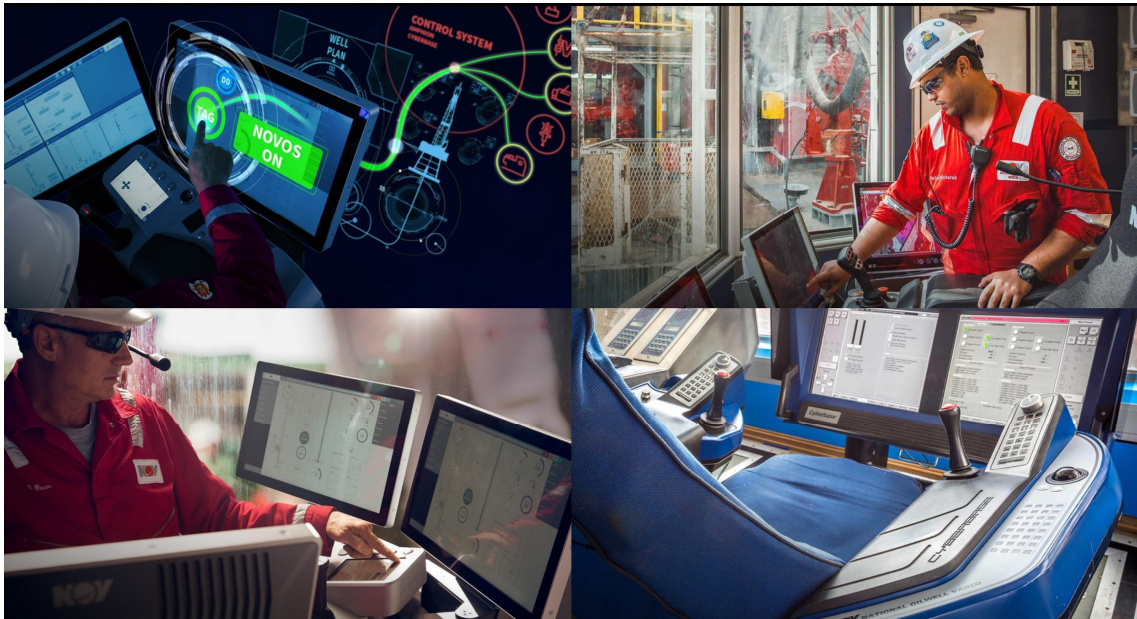


Figure 2.2: Driller chair[<https://www.nov.com/products/drilling-control-systems-and-rig-automation/contactus>]

Figure (2.2) shows the driller's chair, which allows the driller to obtain all information and monitor what is happening in the system in graphical forms.

2.3.3 Modeling

The next step after monitoring what is happening in the system is developing an appropriate model or a prediction that tells us what will happen in the future.

The development of the model begins with understanding the problem represented to achieve an appropriate prediction of system behaviour. A well-trained model will be generated with the optimal parameters. For instance, the drilling speed, called rate of penetration (ROP) in drilling system can be predicted more accurately based on actual drilling data, so strategic decisions based on data analysis and interpretation methods are used to build ROP prediction models.

The appropriate model can be generated in drilling system such as temperature model, Managed Pressure Drilling (MPD) model, torque and drag model, etc.

2.3.4 Controlling

In this step, the system behaviour is being regulated by the control system by using control loops. Based on defining the objective and required set-points and achieving an appropriate developed model, the controller whose an essential role in the control system can be designed.

The Feedback, Feedforward, and Proportional Integral Derivative (PID) controller based on control loops adjust the deviated output because of different disturbances in the processing system to obtain the desired results.

2.4 Control System

A control system is a system, which regulates and adjust the output to provide the desired results by using control loops and controllers.

2.4.1 Classification of Control Systems

Control systems are classified into two basic types of control, open-loop and closed-loop control system. In open-loop control systems, the output does not have any effect on the control system, i.e. it doesn't have the feedback, and this is why it is called a non-feedback control system see (2.3b). In a closed-loop system, the output has a direct effect on the control process in the sense that closed-loop control systems are referred to as feedback control system see (2.4b).

Open Loop Control System

The advantage to open-loop systems is that they're typically pretty cheap, simple in construction and design, and there's no way to change output states if the process deviates from its required state. The open-loop control systems are used in Electric Hand Drier, Automatic Washing Machine, Bread Toaster and Automatic Tea/Coffee Maker.[1]

Closed Loop Control System

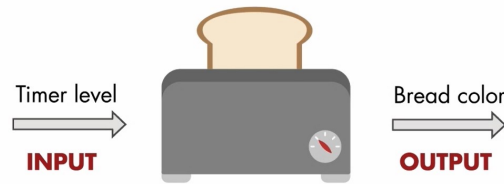
The advantage of the closed-loop control system is that it is usually more accurate even in the presence of non-linearity. In closed-loop control, a feedback loop is included, which provides information on the status of the process to the process controller and adjusts the process to become self-regulating. Feedback loops can be found in Water Level Controller, Cooling System in Car and Servo Voltage Stabilizer.[2]

Figures (2.3) and (2.4) illustrate how the Open-loop control system and Close loop control system work with a bread toaster example.

2.4.2 Control Algorithm

In control engineering, there are several different control algorithms applied in drilling operations. One of the essential applications of control engineering is maintaining a bottomhole pressure as required during the drilling operations by using control engineering methods to manage the pressure during the drilling MPD. The control algorithm is developed following the steps [68]:

1. Define the variable that we are going to control.
2. Dynamic modelling.



(a) Open loop control system example
<https://se.mathworks.com/videos/understanding-control-systems-part-1-open-loop-control-systems-123419.html>



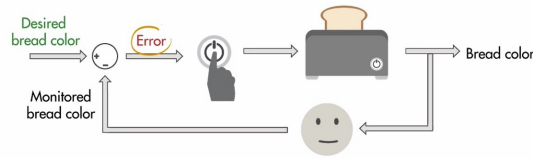
(b) Open loop control system
<https://instrumentationblog.com/what-is-control-systems>

Figure 2.3: Open Loop Control Systems

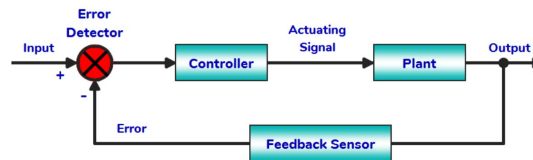
3. Design the appropriate controller based on model(illustrate control system terminology).
4. Simulation.
5. Implement and Tune.
6. Performance of control system.

The figure 2.5 of control system terminology is a typical method that illustrates the control system and the process taking into account the following terms below [33]:

- r : reference value.
- y : measured value or controlled value (CV).
- e : error between the reference value and controlled value.
- u : manipulated value.



(a) Closed loop control system example.
<https://se.mathworks.com/videos/understanding-control-systems-part-1-open-loop-control-systems-123419.html>



(b) Closed-loop control system
<https://instrumentationblog.com/what-is-control-systems>

Figure 2.4: Closed Loop Control System

- x : process state variable.
- v : process disturbance variable.

2.4.3 PID Controller

The most common control algorithm called the PID control algorithm. The widespread of PID controllers in the industry nowadays is due to the ability of these controllers to compensate for many practical industrial processes.

What is PID controller ?

The PID controller is an acronym that stands for:

- P- Proportional
- I- Integral

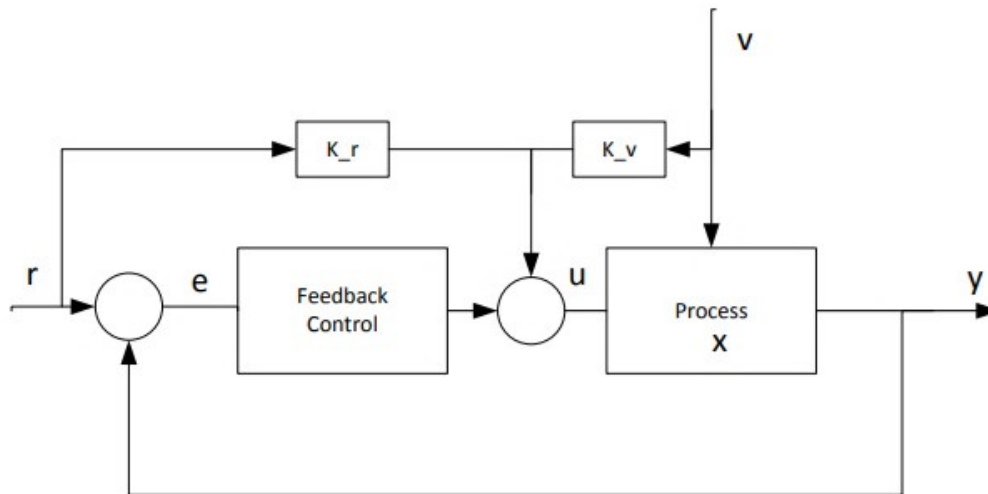


Figure 2.5: The control system terminology

- D- Derivative

PID is a method used in industry to regulate the output variables and keep them constant values as required by using a control loop feedback mechanism. See Figure [2.7]

The difference between the P, PI controller and PID controller and trier gain can be illustrated in the tables [2.1] and [2.2] bellow [11] in which the five most essential characteristics are [8]:

Parameters	Speed of Response	Stability	Accuracy
increasing K	Increase	Deteriorates	Improves
increasing Ki	Decrease	Deteriorates	Improves
increasing kd	Increase	Improves	No impact

Table 2.1: Comparason Of Gain Response Of P, Pi And pid Controllers

It is a demand to take advantage of the following features when designing an ideal controller:

- Using KP to decrease the rise time.
- Using KD to reduce the overshoot and settling time.
- Using KI to eliminate the steady-state error.[68]

Parameter	P Controller	PI Controller	PID Controller
Rise time	Decrease	Decrease	Minor Decrease
Overshoot	Increase	Increase	Minor Decrease
Settling time	Small change	Increase	Minor Decrease
Steady state error	Decrease	Significant	change No change
Stability	Worse	Worse	If Kd Small Better

Table 2.2: P Controller, PI Controller and PID Controller effect

1. Rise Time: The time it takes for the response to rise from 10 to 90 per cent of its final value

2. Overshoot:

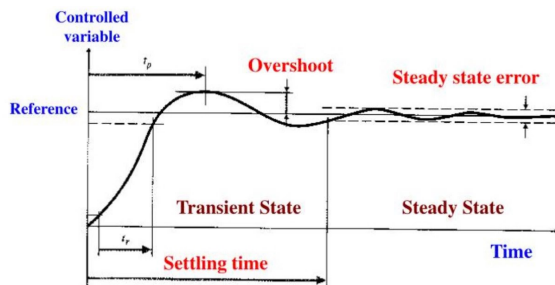
$$OverShoot = Y_{max} - Y_{ss} \tag{2.1}$$

(Ymax) for maximum output values, and (Yss) for the steady-state value of output.

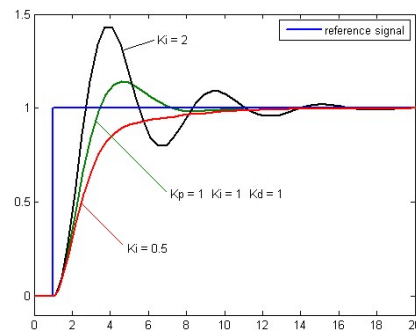
3. Settling Time: The time required for the response to stay within a range of a certain percentage of its final value (2 per cent)

4. Steady State Error: The difference between output and input of a system where the time goes to infinity.

5. Stability



(a) P Controller Response
<https://www.slideserve.com/gil-rasmussen/control-systems-for-robots>



(b) Ki, Kp, and Kd
https://en.wikipedia.org/wiki/PID_controller

Figure 2.6: P, PI and PID controller

Figure [2.6] illustrates the PID response and the effect of the controller’s gain Kp, Ki and Kd

The error can be defined as the difference between the setpoint and the process variable sent to the PID controller.

The control signal (u) is sent from the PID controller to the plant equals to the

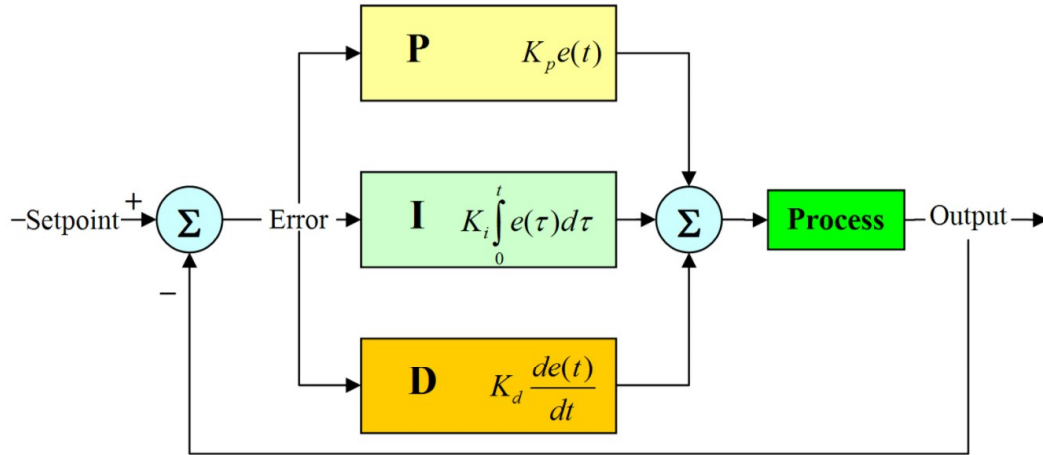


Figure 2.7: PID structure

<https://maldus512.medium.com/pid-control-explained-45b671f10bc7>

controller bias (u_0) where $(e(t)) = 0$, plus the proportional gain (K_p) times the magnitude of the error ($e(t)$) plus the integral gain (K_i) times the integral of the error plus the derivative gain (K_d) times the derivative of the error $\frac{de(t)}{dt}$. The PID controller is given in the equation below that can be used to manipulate the control signal (u)[33].

$$u(t) = u_0 + K_p \cdot e(t) + K_i \cdot \int_0^t e(\tau) \cdot d\tau + K_d \frac{de(t)}{dt}. \quad (2.2)$$

2.4.4 Simulations

Nowadays, many industries, including the petroleum industry, need more adaptable production system to manufacture products faster and with a high level of process optimization. It is required a flexible automation system can establish an appropriate communication with the real world physical process.

Simulation is an essential step in the basic process which includes data acquisition, data analysis, modelling and simulation, predication and then controlling is the implementing and process of mathematical modelling. Then the computer can run the algorithm which is designed to predict the behaviour of the real-world system and this processing. The sensor signals are processed by virtualization tools to display the variables and processing on the human-machine interface (HMI) in real-time. Simulation of communication systems is usually done by computing the response of a system to random process samples using a computer program. There are many simulation platforms used to obtain the necessary process, such as Matlab Simulink.[31]

MATLAB is a programming environment for algorithm development and data analysis visualization numerical computation. It is one of many simulation software examples that could provide data test algorithms that are afterwards implemented in the processing system.

Chapter 3

Drilling Automation Tools

3.1 Introduction

3.1.1 Drilling Automation

After the discovery of hydrocarbon energy sources, a paradigm shift in industry history, and after drilling the first drilling well on Aug. 27, 1859[18], the oil industry has witnessed many problems and hazards that resulted in human and economic losses. This was one of the reasons to promote the oil companies to develop drilling and production methods until automation was introduced in most drilling operations, i.e. drilling fluid systems, ROP optimization, well integrity, cementing operations, downhole automation, and the rig floor to obtain desired results.

During the last decade, there has been a growing interest in the evolution of technology and autonomous system in drilling operations, focusing on the fully automated system or so-called robotized system to replace manual labour.

The convergence of two major trends, automation and mechanization, helps to distinguish between drilling automation and rig floor automation, which deals with mechanized surface activities, in which human physical labor is substituted by machinery in the mechanization process. However, in certain cases, such as current rigs with highly automated pipe-handling systems, the human still controls the machines, but in automation systems, the human intervention has been reduced to the point where the computer controls the machines after processing stages.

Drilling automation based on supervisory control, computer and human monitoring estimates the downhole behaviour and its physical measurements with near real-time. Measurements can be transmitted to the surface through wired connection with components in the bottom hole assembly (BHA). The data is being used for analysis, predictions and development of new models. [48][72][71]

Drilling Automation has shown to improve the performance of the drilling operation compared to more manual control and monitoring of the process. Among the benefits of using automation in drilling operations are [49][27][48][32]:

- Minimizing humans' involvement: reduces the risk and hazards that workers may face
- High accuracy and finish: high levels of accuracy can be achieved with an

automation system for the same tasks humans perform.

- Flexibility: Automation can be flexible and specific to perform the tasks based on the equipment configuration.
- Consistency: The same task can be repeated many times with the same consistency compared with the levels of achieved consistency by humans.

The impact of an automated drilling system is illustrated by the drilling efficiency improvement and reducing the costs. Using Halliburton’s automated rig activity is an excellent example to illustrate the automation efficiency in drilling operations. Reducing the Non-productive time (NPT) is one of the automated drilling system advantages, in which NPT methods rely on pipe stuck and Rate Of Penetration (ROP) as indicators of NPT. The 2013 IADC Critical Issues Asia Pacific Conference, 20-21 November in Bangkok, illustrates that automated rig activities can help for saving money and time.

Halliburton’s automated system is based on a standard algorithm that is applied to activity analysis. This can be applied for several rig operations, including drill speed, bit depth, flow rates, rotational speed and hook-load or in-slips measurements and this analysis can be divided into three essential activities, tripping in, tripping out, which can be defined by the riser, casing liner and open-hole environment, and drilling. [45]

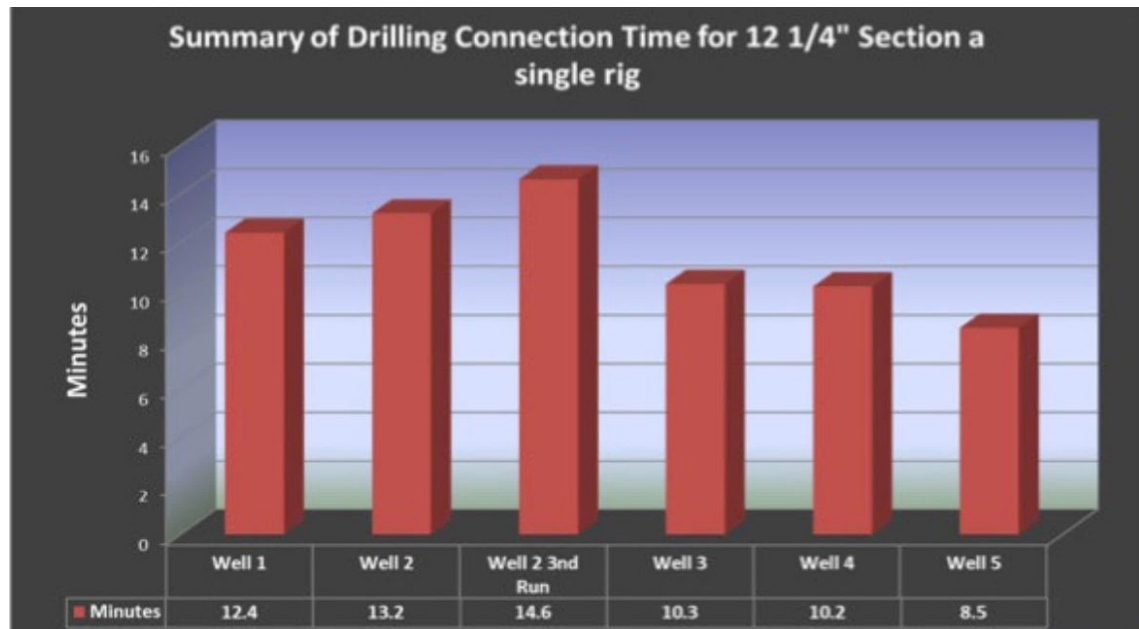


Figure 3.1: Halliburton’s automated rig

Figure [3.1] shows the connection times which is reduced to 8.5 min after several wells/ the reduction of 172 min for the 12 1/4 in section/. Using Halliburton’s automated rig activity measurement and reporting identification system, an operator

in the Asia Pacific was able to reduce connection times in 12 $\frac{1}{4}$ -in. well section by a total of 172 minutes.

Automation is trending nowadays to demonstrate the oil and gas industry broadly. It is being used in several offshore applications to obtain the optimization drilling process, for instance, Managed pressure drilling (MPD), Expandable tubular technology, High speed well communication, Rotary-Steerable System (RSS) and Steerable drilling liner, Real-Time Bit Tracking With Seismic, semi-autonomous is the bottom hole assembly, i.e. MWD, LWD, and PWD, real-time interpretation methods such as well placement, reservoir mapping and Geo-steering, Drilling fluid Rheology and properties, drilling fluid pumps system, Cementing operations.

3.1.2 Drilling automation system review

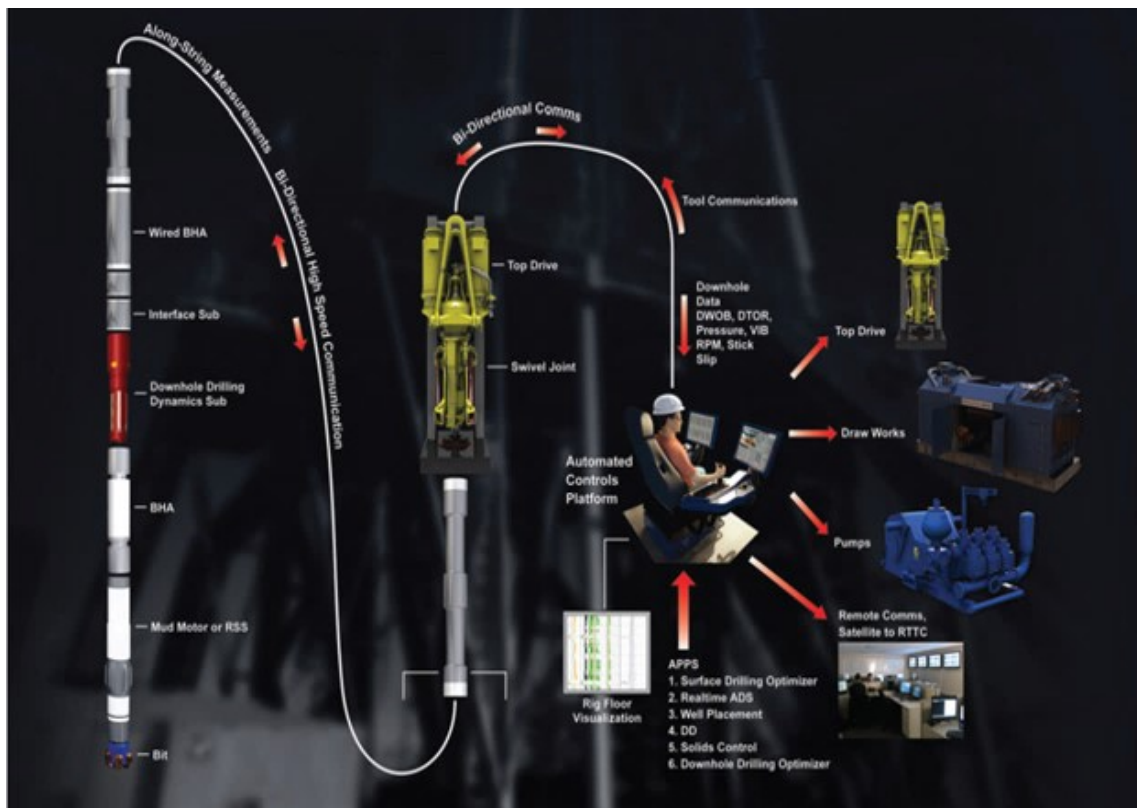


Figure 3.2: Automated Well Construction System

<https://www.aogr.com/magazine/cover-story/automation-of-downhole-surface-components-optimizes-drilling-process>

The figure 3.2 represents an automated system review that can be used on every type of rig without retraining the crew when moving to another rig.

Closed-Loop Downhole Automation (CLDA) and Process Automation System (PAS) can make up the integrated drilling automation system when they are both combined. The effectiveness of CLDA can be seen in improving on bottom rate of penetration (ROP), bit run lengths, and reducing the number of trips that occur due to downhole tool failure. At the same time, PAS allows moving from machine controller to process controller, run the rig without conservative safety margins, it

helps to run the processing full automatically on the bottom. The impact of CLDA and PAS on the drilling process while drilling the first two 12 $\frac{1}{4}$ -in. hole sections can be shown in the example below: [58]

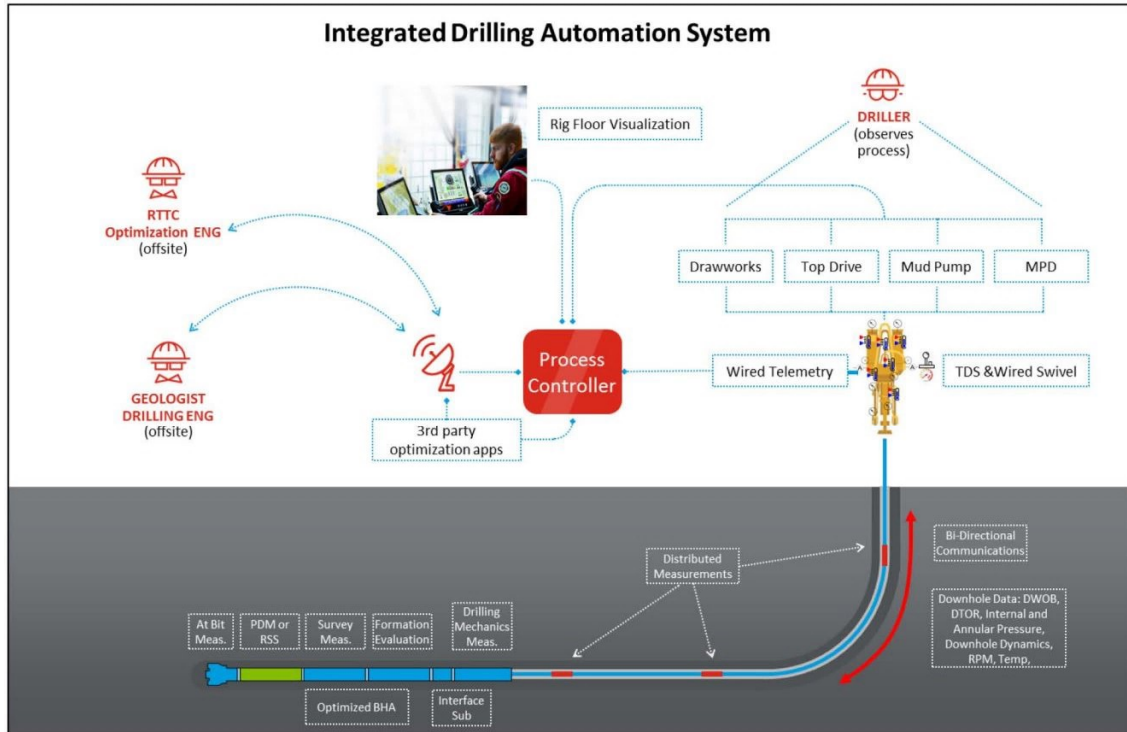


Figure 3.3: Integrated Drilling Automation System

Figure [3.3] illustrates the Integrated Drilling Automation System, which comprises two systems, PAS and CLDA.

PAS System: It is the software that allows the drillers to carry out the drilling process automatically. There are many control points in the system that determine how the bit engages the formation, for instance, changing the bit RPM before formation engagement, bit RPM after an engagement, flow rate before and after bit engagement, etc.

The additional hardware for this system is minimal and plugs directly into the controller cabinet or (PLC) house. It is necessary to design a well plan that allows the driller to know the types of drilled formations, depth, hole size, and last casing location, which aids the driller in anticipating and describing the drilling process behavior. [58]

CLDA System: The goal of the Closed-Loop Downhole Automation (CLDA) service was to minimize the amount of time spent drilling. The CLDA service resulted in a net savings of 32 percent, with the section being drilled in 5.9 days for a total net savings of 2.8 days.

Drilling Mechanics Sub

It is a tool that provides real-time and memory data of the following parameters: downhole WOB, downhole torque, lateral/angular acceleration, Z (axial) acceleration, external and internal pressure, temperature, gyro-derived RPM, and bending moment. [59]

Wired Drill Pipe (WDP)

This tool will be expanded on in a subsequent paragraph.

DWOB Controller

Real-Time Downhole Weight on Bit controller DWOB uses the software and rig equipment to obtain the desired DWOB value.

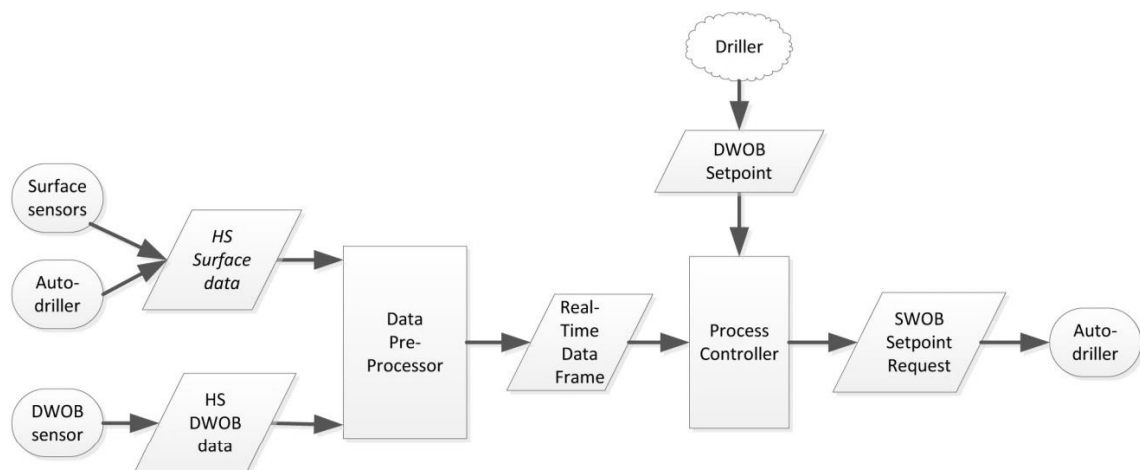


Figure 3.4: DWOB controller system diagram

Figure [3.4] shows the system components and data flow through the DWOB controller.

The system operation can be defined as follows [59]:

- High-speed surface measurements and auto driller operational data (surface sensors), input.
- High-speed measurements of downhole (WOB) (DWOB sensors), input.
- The data pre-processor describes the inputs and generate the data frame on a fixed time (Real-time data frame).

- The process controller which analyzes the Real-time data frame and computes (SWOB) surface WOB setpoint.
- The auto driller receives the SWOB setpoint and carry out the required SWOB after analysing SWOB setpoints.

Surface Stick-Slip Mitigation Software

Stick-slip or drill string vibration is caused mainly by drilling torsional oscillation during drilling. The stick-slip can be extended to include the Bottomhole assembly and could damage the bit. A mitigating stick-slip method by increasing RPM or decreasing weight on bit (WOB) is used to mitigate stick-slip vibration incident.

[40]

Surface Stick-Slip Mitigation Software is a software algorithm that helps determine dampens and inhibit the reflection of torque caused by the drillstring vibrations. Top-driver speed, torque track and drillingstring's effective deficiency are being monitored by the software and then manipulate the top-driver system to reduce the torsional induce and prevent stick/slip motion that occurs along the drillstring.

[52]

3.2 Drilling automation tools

The oil and gas industry has seen tremendous automation in recent years, with drilling automation being seen as the industry's future. The development of petroleum technology needs a larger emphasis on innovation and downhole measurements as an alternative to tackling conventional well operation challenges. Essential aspects of the drilling automation system include drilling automation tools that provide effective downhole connection and data transfer.

3.2.1 Wired Drill Pipe (WDP)

Oil and gas companies have faced a number of challenges while drilling wells, particularly in High-Pressure High Temperature (HPHT) wells, deep water wells, and other wells with a narrow geo-pressure margin, which has necessitated an increase in demand to tackle these issues.

Previously, data from downhole measurements could be accessed during drilling utilizing wired drill pipe, which offers a high-quality transmission network for real-time measurements from the wellbore to the surface, hence improving drilling processes. The necessity to transmit high-quality, high-speed data from a well downhole to the surface in order to address drilling problems prompted the development of data transmission technologies that evolved away from conventional mud pulse telemetry technology and toward Wired Drill Pipe technology.

Figure [3.5] shows the optimization drilling performance using high-speed telemetry and closed-loop digital platform based on BlackStream™ downhole sensors and IntelliServ™ wired drill pipe, enabling bi-directional transmission of downhole data to acquire the downhole measurements at high speed.

Clarity and accuracy data can be available to the drillers during virtualization and analysis in which IntelliServ wired drill pipe provides the speed data transmission up to 57,600 bits per second. [55]

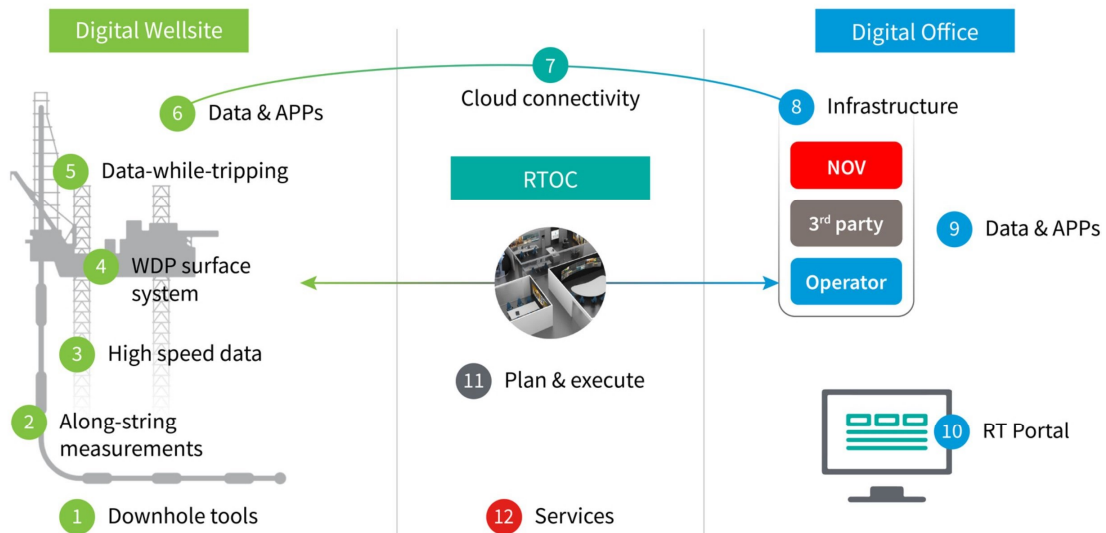


Figure 3.5: Downhole Broadband Solution
<https://www.nov.com/products/downhole-broadband-solutions>

Advantages of using WDP telemetry technology

[64]:

- The rig time saving since it can supply the drillers speed transmitted data which gives the information about downhole measurements, hence facing the different drilling challenges.
- the acquired real-time data from WDP was used to optimize the wellpath and reservoir exposure, mainly when it used to improve the ROP continuously during drilling in the well and the reservoir section.
- Reliability of wired drill pipe network and the high quality in evaluating the formation results in optimized geosteering.
- By measuring internal and annular pressure, temperature, and other variables, ASMs sensors are used to monitor wellbore conditions such as equivalent circulating density (ECD), detection of an early kick in the well, and lost circulation.
- Using WDP telemetry technology is not only rig time saving and ensuring the optimization drilling process with high speed of data transmission during

the drilling operation, but it also improves safety and mitigates the risk rate during the drilling process.

Figure [3.6] shows the advantage of NOVOS system in decreasing costs, improving ROP and efficiency of drilling by Mechanical Specific Energy (MSE), which works in harmony with wired drill pipe in Alaska North Slope r-process automation achieved 95 percent up-time with wired drill pipe and improved overall drilling performance on project wells versus offsets. [54]

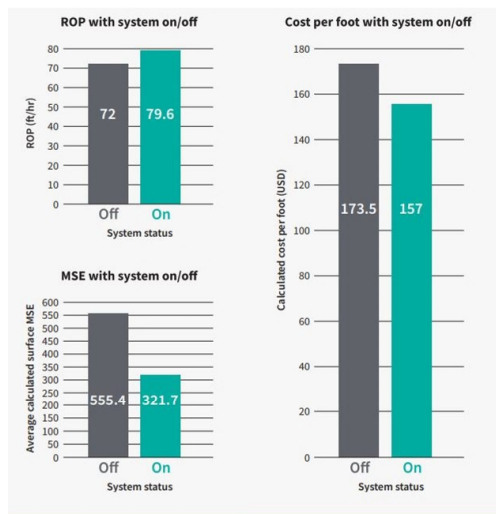


Figure 3.6: NOVOS SYSTEM EFFICIENCY

3.2.2 Along string measurement (ASM)

WDP technology opens up new possibilities for communication between the down-hole and the surface using various sensors. AlongString Measurements (ASM) is made up of several sensors that are part of the wired drill pipe network technology and may be placed at various locations along the drill string.

As part of the WDP, ASMs provide network connectivity by measuring physical parameters from the downhole and aiding in the transmission of data from the downhole at high speeds to be visualized on the drill floor in realtime, even when the flow is off.

The benefits of ASMs include identifying pack-off points and assessing downhole incidents, as well as early indication of a kick by using annular/internal pressure and temperature sensors. Along String Measurements are acquired rotation and vibrations data at high frequencies, which can help to describe the borehole conditions along the drill strings and at Bottom Hole Assembly. ASMs can also help visualize

realtime hole cleaning and adjust parameters, such as ROP, RPM, and flow rate.[56]

National Oilwell Varco (NOV) provided the oil and gas industry with NOV's BlackStream alongstring measurement (ASM) tools as a part of WDP components, see [3.7], which has a flexible placement along the drill string. BlackStream ASM tools are used to evaluate the dynamic environment of the drillstring by equipping to temperature, annular/internal pressure, three-axis vibration and rotational velocity sensors. The BlackStream ASM tool can also acquire real-time equivalent circulating density data. It is connected to the IntelliServ networked drill string that helps obtain the high quality of downhole information that aims to optimize drilling process elements such as pressure profile and wellbore condition.[3]

Figure [3.7] illustrates the components of IntelliServ Network, which has six main components to run the system as follows:

- DataSwivel™
- NetCon™ and Surface Cabling
- Wired Drill String and components
- DataLinks™
- BlackStream ASM and EMS
- BHA Interface Sub

Different types of sensors can be distributed along the drillstring, as follows:

- Pressure sensors.
- Temperature sensors.
- Strain gauges.
- Inclinometers.
- Accelerometers.
- Bending, vibration, and rotation sensors.
- Flow-rate sensors, and many more.
- Sensors measure wellbore stability, resistivity, ECD measurements.

Figure [3.9a] shows A high-bandwidth data transmission system using networked drill string's distributed downhole pressure and temperature measurement sensors which allow evaluating the wellbore condition from downhole to surface.[77]

Along String Measurements implements

It can be utilized to distribute the ASM along the drillstring in the wellbore in several drilling methods and solutions. For instance:

Monitoring hole cleaning

ASMs to detect early kick incident

Many challenges and well incidents occur when the drilling operations are based on only the surface measurements or when drilling a deepwater well and the data flow

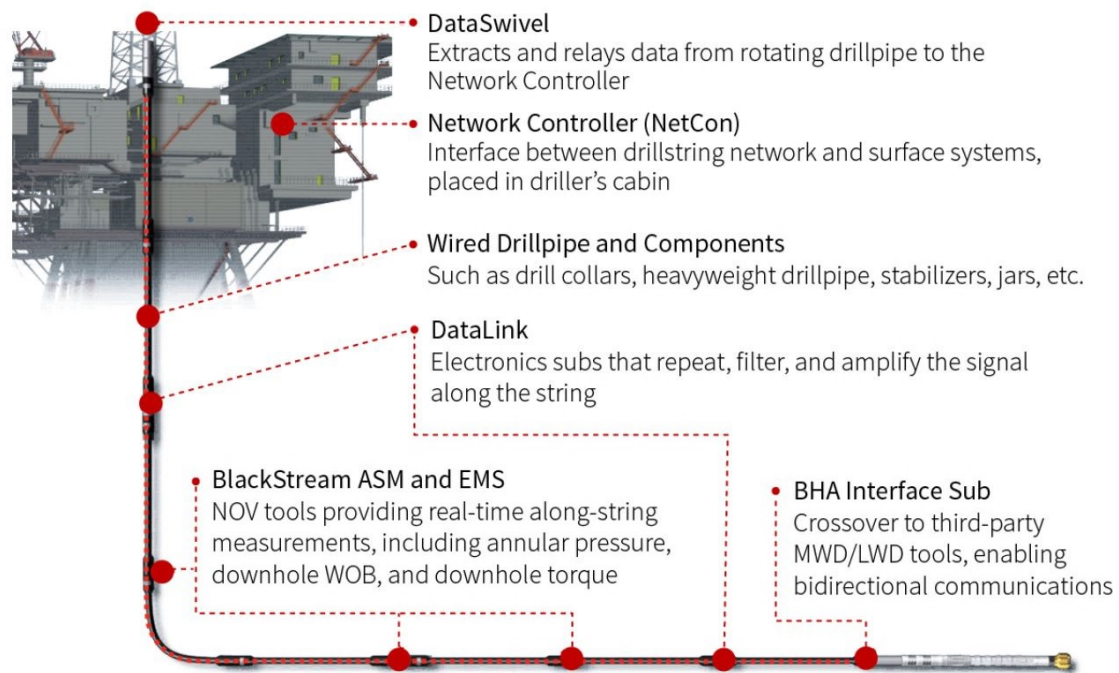


Figure 3.7: overview of the IntelliServ network including the BlackStream ASM
<https://www.hartenergy.com/exclusives/highway-downhole-data-delivers-optimized-drilling-176314>

is too slow. Formation influx which leads to kick in the wellbore is one of these incidents, and early detection of the kick is demanded to face this challenge and avoid blowout risk.

Along string pressure sensors are distributed near the bit and along the drill string to pressurize the annulus and measure the pressure changing along the wellbore. This implement help to early detect the kick to run the Managed Pressure Drilling system, which adjusts the ECD to circulate the kick automatically.

Figure [3.8] below is an example that shows the kick occurring in the well and flowchart decision to detect the kick. Four sensors are distributed along the drill-string to record the annular pressure in time $t=(0,1,2,3)$. The first sensor, which is located nearest the bit, records the annulus pressure change when the corresponding pressure gradient is reduced due to the formation influx, and the other sensors record the annulus pressure change when the high kick starts decreasing and reaching the sensors where are placed above. The network drill pipe system delivers a response time of fewer than 10 seconds to begin the kick circulating and keep the safety pressure margin well [77].

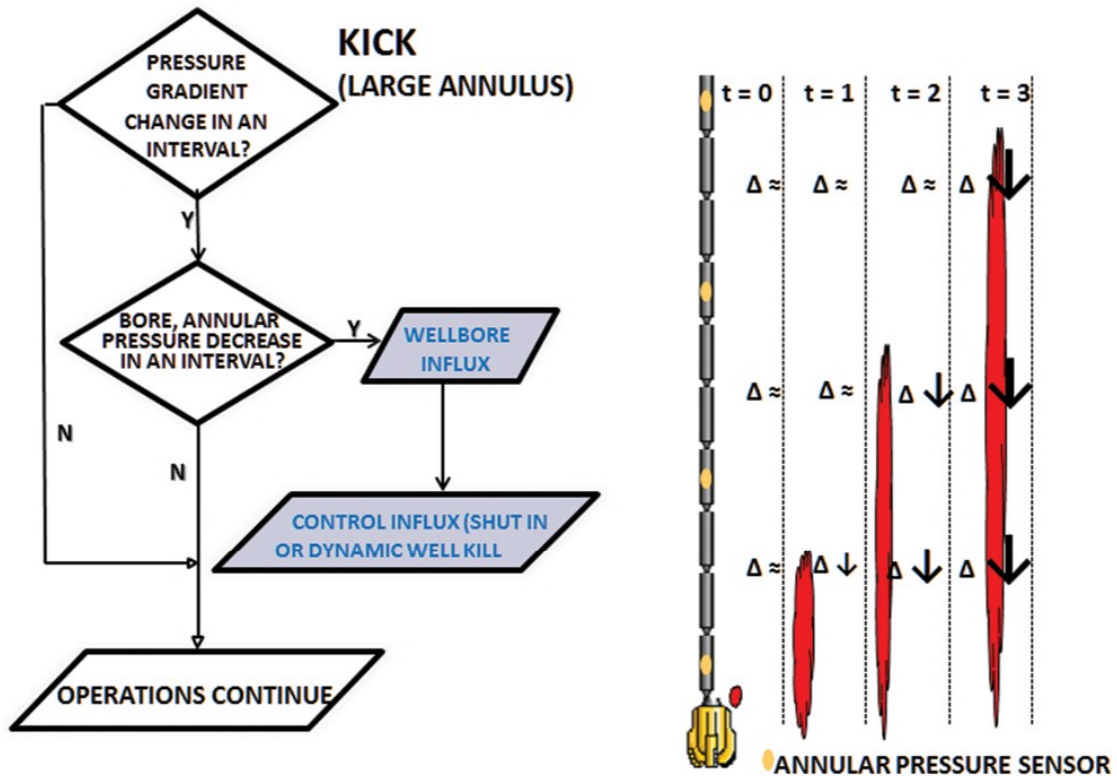
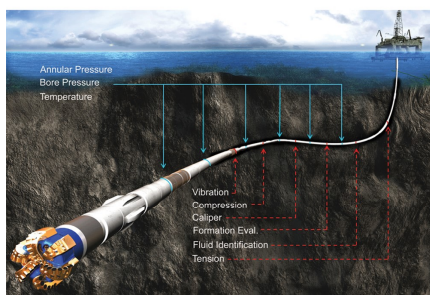
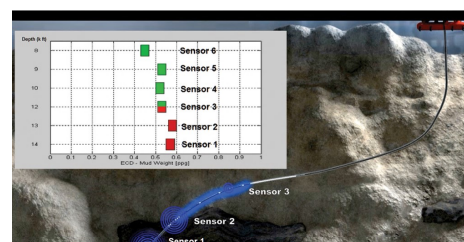


Figure 3.8: ASMs Kick and FlowChart

Figure [3.9b] shows six along-string annular pressure sensors record the dynamic pressure over the mud weight, revealing the location of fluids within the annulus using Downhole data provided by the wired drill pipe, which aids in the analysis of fluid migration in the annulus. It also illustrates that the influx would cause a pressure reduction, whereas kill mud traveling up the annulus would induce a pressure raise.[77]



(a) Networked drill string's distributed pressure and temperature measurement
<https://www.drillingcontractor.org/wired-pipe-delineates-safer-drilling-margins-2-14010>



(b) s. Six along-string annular pressure sensors record the dynamic pressure over the mud weight,
<https://www.drillingcontractor.org/wired-pipe-delineates-safer-drilling-margins-2-14010>

Figure 3.9: Along String Measurements ASM

Chapter 4

Drilling Fluid Properties

4.1 Introduction

Oil and gas companies have aimed to improve the drilling process by minimizing well expenses and guaranteeing that the task is completed at the most opportune time with the minimum drilling challenges possible. Hence, selecting a drilling fluid with optimal properties was one of the most important aspects of maintaining well integrity and managing the drilling system, thus attaining optimal drilling results.

Choosing a proper drilling fluid has been an essential factor during the drilling process. Furthermore, most typical drilling issues, such as lost circulation, influx, stuck pipe, caving shales, rate of penetration and cuttings transport, are directly or indirectly linked to the rheology and properties of selected drilling fluid. Drilling fluid properties such as Density, Viscosity, Gel strength, and Filtration have the primary role in determining the behaviour of drilling fluid and drilling fluid flow in the wellbore. The selected property has a direct and indirect impact on the quality of drilling process, notably the bottomhole pressure, and hence wellbore stability.

4.2 Rheology

Professor Bingham is credited for coining the term "rheology." Rheology is the study of fluid deformation and flow, which can be accomplished by studying the characteristics and behavior of fluids. Studying rheological models can be used as a simulation of the properties of the drilling fluid.[10].

Figure [4.1] shows the different rheological models and fluid behaviour which express the relationship between the Shear rate and Shear stress.[6]

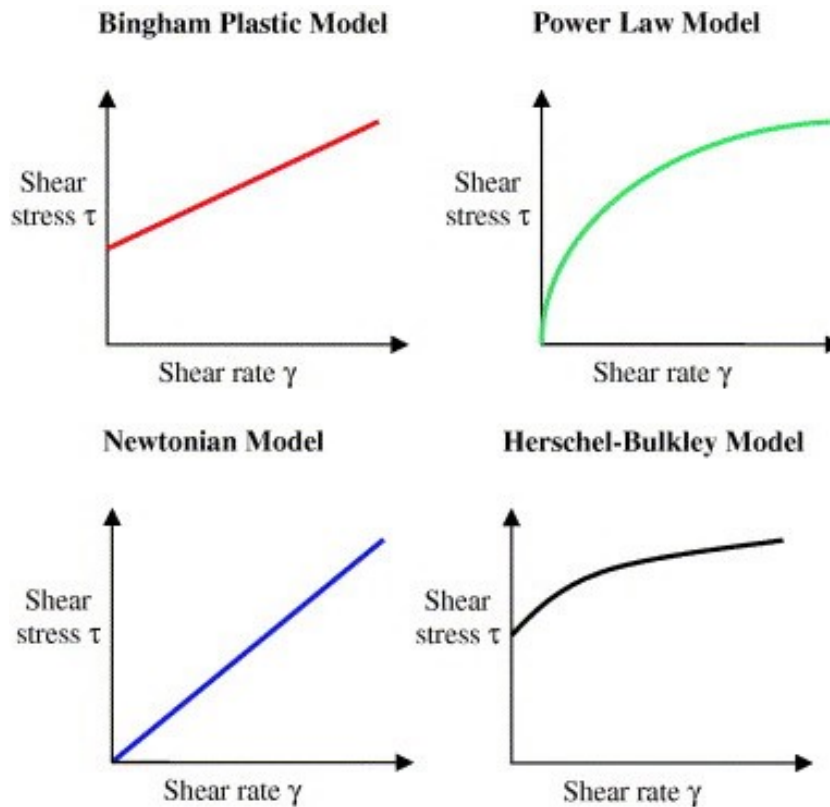


Figure 4.1: Rheology Models

There are several types of fluids that have been classified into two categories based on their flow behavior and time-depend as follows:

- Newtonian fluids, also known as time-dependent fluids, include water, light crude oil, and gases. Newtonian fluids exhibit a linear relationship between shear stress (ζ) and shear strain rate (γ), and constant viscosity independent of pressure.
- Non-Newtonian fluids, can be time-depend or non time-depend fluids, such as chocolate, blood, and paint. Non-Newtonian fluids have no constant viscosity, nonlinear relationship between shear stress and shear rate, and do not obey Newton's law of viscosity.

Furthermore, it has been determined three different types of flow regimes, describing the behavior of the drilling fluid in the well. The Flow regimes that govern the drilling fluid's manner and behavior in the well are shown in the figure [4.2]. One of the most critical factors that distinguishes these three types of flow regimes Reynolds number:

- Laminar Flow $Re < 2300$
- Transition Flow $2300 < Re < 4000$
- Turbulent Flow $4000 < Re$

$$Re = \frac{\rho \cdot V \cdot D}{\mu} \quad (4.1)$$

where

- ρ : *density*(kg/m^3)
- V : *velocity* (m/s)
- D : *pipe diameter* (m)

- μ : *viscosity*($pa.s$)

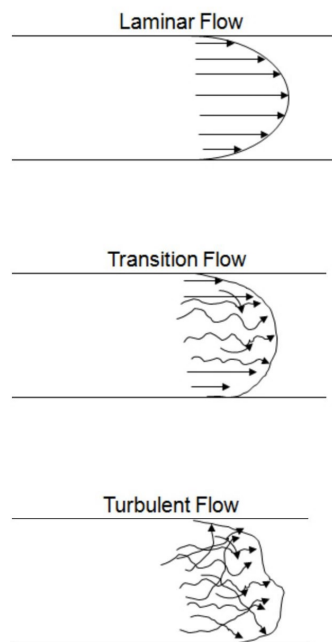


Figure 4.2: Flow Regimes

To comprehend drilling fluid rheology, it is necessary to expand on understanding of viscosity, which is one of the major properties used to characterize drilling fluid rheology with Bingham plastic fluid parameters and yield point (YP).

4.3 Drilling fluid properties

One of the most important factors to achieve an optimal drilling performance and minimize drilling hazards is choosing the proper drilling fluid properties during drilling operations.

4.3.1 Viscosity

Drilling fluid viscosity can be defined as a fluid resistance to flow. Viscosity represents the friction force due to interaction between the fluid particles and solid. It is

also expressed as a ratio between shear stress and shear rate.[41]

$$\mu = \frac{\text{ShearStress}}{\text{ShearRate}} = \frac{\zeta}{\gamma} \quad (4.2)$$

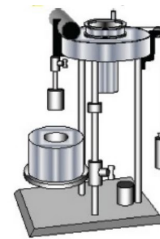
where centipoise (cp) is used as a drilling fluid viscosity measurement unit.

Different viscosity measuring devices are used to measure this property. See figure [4.3] which shows the different viscosity measuring devices [41] such as :

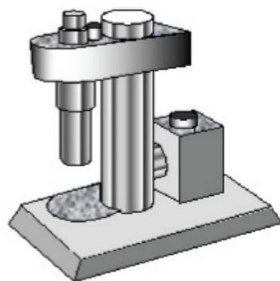
- Marsh Funnel is used to measure effective viscosity and to check the quality of drilling fluid
- Stormer or Rotational viscometer
- Fann viscosity and gel device
- HPHT pressure viscometer



(a) Marsh Funnel



(b) Stormer



(c) Fann V.G device



(d) HPHT pressure viscometer

Figure 4.3: Different viscometers

The viscosity property has a significant impact on cuttings suspension and transport during the drilling operation. Hence, increasing viscosity results in improving the cutting transport performance while velocity and inclination of the well are constant, this impact of viscosity will be discussed further in this chapter.

4.3.2 Gel strength

The gel strength is the gelatinous and attractive force between fluid molecules, which is necessary to keep the solids suspended under static and non-rotation conditions. The chemical materials are used to obtain the optimal drilling fluid with enough gel strength even in high temperature, high-pressure condition.

One of the most essential drilling fluid features is gel strength, which is used to guarantee that the drilling fluid suspends the cuttings in the well, preventing the formation of a cuttings bed and drill pipe stuck, and thereby reducing costs by minimizing non-production time (NPT).

Gel strength is being measured by viscometer, using three rpm readings for (10 sec, 10 min, 30 min) respectively.[22]

In terms of rheology, high viscosity and gel strength result in an appropriate borehole cleaning due to providing a reasonable suspension of weight material. Low viscosity and gel strength result in faster drilling and the more efficient separation of drilled solids [66].

4.3.3 Control Filtration

The driller adjusts the drilling fluid density such that the annular pressure is higher than the pore pressure. The difference between hydrostatic pressure and pore pressure may allow drilling fluid to invade the porous and permeable media around the well, causing formation damage, borehole stability, and, in certain cases, circulation loss. To limit drilling fluid loss into formations, a filter cake (of appropriate thickness and quickly flushed with backflow) was required.

Figure ([4.4] is taken from [5]) shows the drilling fluid process and (HP-HT) filter press for filtration test.

The filter cake is an accumulation of solid drilling fluid constituents that generates an impermeable mass that prevents drilling fluid from filtration and plugs the pore spaces. [29].

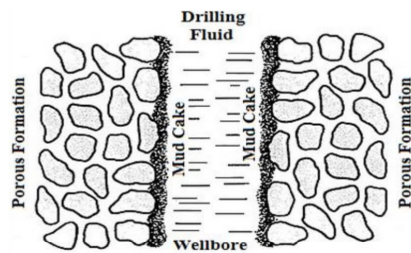


Figure 1. Drilling fluid filtration process.



Figure 2. HT-HP filter press (500 ml).

Figure 4.4: Drilling fluid filtration process and filtration test

The filtration control materials are being used to reduce drilling fluid loss due

to the difference between pore pressure and hydrostatic pressure.

The common additives have been used to control the filtration are :

- Polymers, i.e. Sodium Carboxymethylcellulose (CMC), reduce the loss by increasing the effective viscosity
- Bentonite is used to control the filtration, viscosity and suspension as well.
- Starch is used to plug the pore spaces in the filter cake.

Oil-Based-Mud (OBM) has better properties regarding mud (drilling fluid) filtration than Water-Based-Mud (WBM), and it is barely demand to filtration control additives when using OBM [41].

The filter press instrument and a special high pressure and high temperature device are two types of filtration test instruments used to determine the filtration rate.

The filtration rate is defined as the volume of liquid passing filter cake into formation in a specific period under given pressure and temperature conditions [41].

4.3.4 Density

Drilling fluid density, or so called mud weight, is defined as a mass per unit volume.

$$\rho = \frac{m}{v} \quad (4.3)$$

Where (m) is mass (kg or pound) and (v) is a fluid volume (m³ or gallon). The drilling fluid density is normally measured in (kg/m³) according to SI units, (lb/gal or ppg) pound per gallon as a field unit and (kg/cm³) or as it is called (SG) specific gravity.

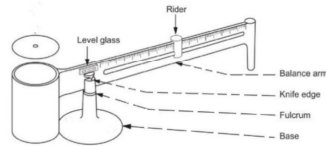
Drilling fluid density is expected to have a substantial direct and indirect influence in the most of well issues, such as formation influx, lost circulation, fracturing, wellbore collapse, and other incidents which threaten the well integrity.

The drilling fluid density is modified to regulate BHP by controlling the hydrostatic pressure and maintaining the BHP between the pore pressure and the fracturing pressure :

$$P = \rho.g.TVD \quad (4.4)$$

where P : hydrostatic pressure (pa or psi), ρ : density of fluid (kg/m³ or lbm/gal), g: gravitational acceleration (9.8 m/s² or 0.052 in field unit) and TVD true vertical depth (m or ft).

Figure [4.5] shows different methods to measure a mud weight, where figure [4.5a] shows the Mud Balance which is used in a rig side area. Figure [4.5b (URL)] shows density sensors that measure the density of drilling fluid as it exits the wellbore and returns to the surface. Hence, the acquired data measured by sensors is then processed and analyzed.



(a) Mud balance



(b) Mud density sensor

Figure 4.5: Measuring Mud density methods

Barite or hematite and calcium carbonate are the common additives used to increase the drilling fluid density.

4.4 Drilling fluid properties and rheology impact

The impact of density, viscosity and other drilling fluid properties on well integrity and drilling system are visible through their effect on the most critical parameters in drilling operations, and the association between drilling fluid properties and well incidents. For instance, drilling fluid properties impact on bottomhole pressure, Equivalent Circulation Density, cutting transport, MPD method, and the direct impact on kick,lost circulation, stuck pipe,etc.

4.4.1 Bottomhole Pressure (BHP)

Bottomhole Pressure is a significant concern in the oil patch and crucial for HPHT wells, deepwater wells, and other wells with such a narrow pressure margin that can

be defined as the pressure acting on the wellbore walls. BHP effect varied according to the size of the wellbore and drilled formation types, where the wellbore is more prone to drilling incidents while drilling a well with a small diameter, for instance formation influx and lost circulation.

The direct relationship between BHP and the optimal drilling process has led oil and gas companies to develop technologies in order to monitor the state of BHP in the wellbore. The intention was to develop optimal methods to control BHP in a state that guarantees the continuation of the drilling process, prevents drilling problems that increases economic and human dangers, and overcomes the challenges such as [75] :

1. Narrow pressure margin and need to design the pressure profile and mud density control.
2. HPHT wells
3. Mechanical hole stability
4. Drilling unconsolidated and fractured formations etc.

BHP is measured or calculated during well completions, well test and during drilling. Three cases to calculate BHP are as follows [57]:

- BHP is equal to the hydrostatic pressure of the mud column in a static condition (no pumping or no drilling fluid flow) where:

$$BHP = \rho.g.TVD \quad (4.5)$$

Moreover, the density has an evident direct effect on the BHP, in which increasing the density leads to an increase in the BHP, and vice versa.

- When well is circulating, and it begins pumping, the frictions in piping are generated. Hence the BHP is equal to friction pressure (annulus pressure losses) (P_f) and hydrostatic pressure to control the wellbore where :

$$BHP = \rho.g.TVD + P_f \quad (4.6)$$

- By using the MPD method supported by the backpressure pump (is coming later in chapter 6), the BHP is equal to the sum of the hydrostatic pressure, friction pressure, and backpressure (P_b).

$$BHP = \rho.g.TVD + P_f + P_b \quad (4.7)$$

The preceding equations show that drilling fluid density is proportional to BHP. Thus, the need to increase or decrease the BHP may be addressed essentially by altering the drilling fluid density, hence maintaining the BHP in a safe margin.

4.4.2 Equivalent Circulating Density (ECD)

Drilling circulation is the process of pumping the drilling fluid towards the bottom of wellbore through drillstrings, employing the applied pumping pressure to return from bit nozzles towards the surface through the annular between the drillstring and the wellbore wall resulting in a pressure loss. The friction force generated between the drilling fluid and the wellbore wall in the annulus causes the loss of pressure supplied by the pump. This pressure drop, which is absorbed by the formation, can be described as an annular pressure loss.

Equivalent circulating density is the effective drilling fluid density exerted by the circulating process in the wellbore and defined as the sum of the equivalent static density and the annulus pressure loss acting on the formation. ECD can be calculated as follows[50]:

$$ECD = \frac{\Delta Pf}{0.052.TVD} + ESD \quad (4.8)$$

where

- Equivalent static density (ESD) (the fluid is not flowing)(lbm/gal) is an expression of the hydrostatic pressure exerted by a static column of fluid.
- ΔPf is the frictional pressure loss in the annulus (psi), and factors that impact the frictional pressure loss as follows. [23]:
 1. Drilling fluid properties and flow
 2. Hole depth
 3. Cuttings in the annulus and annular clearance
- TVD is true vertical depth (ft)

The ECD is a critical factor and a key issue in HPHT wells, deepwater drilling operations, and other wells with such a narrow pressure margin between the fracture gradient and the pore-pressure gradient, since it has a massive impact on drilling incidents occurrence, such as kick and lost circulation.

In terms of the bottomhole pressure, ECD can express the BHP as follows [15] [35]:

$$BHP = HydrostaticPressure + TotalpressureLossinthewell \quad (4.9)$$

where:

$$ECD(ppg) = ESD(ppg) + \frac{FrictionalPressureLoss(psi)}{0.052.TVD(ft)} \quad (4.10)$$

or

$$ECD(sg) = ESD(sg) + \frac{FrictionalPressreLoss(bar)}{0.0981.TVD(m)} \quad (4.11)$$

Where ESD or current mud weight expresses the hydrostatic pressure when the drilling fluid is not pumping

The factors with impact on ECD

ECD as a function of the TVD, ΔPf and ESD refers to that ECD reduces in the deep wells in which ECD is inversely proportional to TVD. As a result, raising TVD reduces ECD whereas raising ESD increases ECD based on the equations above.

Thermal expansion and then lower equivalent static density are caused by higher temperature, while higher pressures causes compression and an increase in ECD.

Figure [4.6] illustrates that the optimal evaluation of ECD is maintaining the ECD pressure profile greater than pore pressure and lower than fracture pressure, hence maintaining ECD within a safe window.

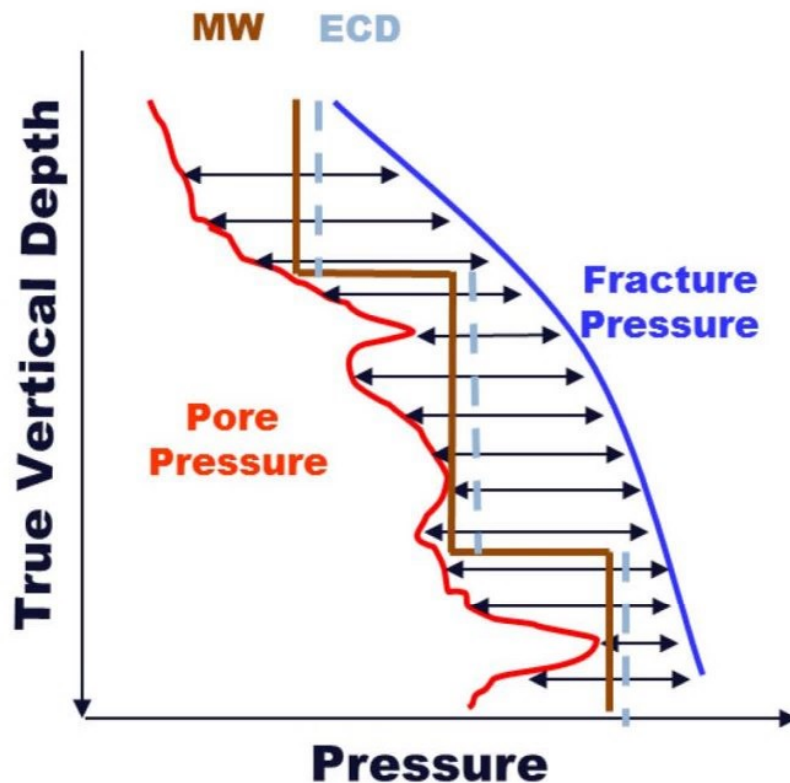


Figure 4.6: ECD in safe window

4.4.3 Cuttings transport

Hole cleaning is one of the significant concern in the drilling operations. Insufficient Hole-cleaning can be induced during applying inadequate mud flow rate and drillpipe rotation, and when selecting improper drilling fluid properties. Monitoring the hole condition and controlling the cutting transport was a demand to achieve an adequate hole cleaning, thus avoid the accidents occurred by inadequate hole cleaning such as drillpipe stuck, excessive torque and drag, problems in the casing, and difficulty in cementing and logging measurement.

Factors with effect on hole-cleaning process

Several factors may affect the hole cleaning performance during drilling operations. Table [4.1] below illustrates the factors those have an impact on the effective hole-cleaning in the borehole [65]:

Factors with effect on hole-cleaning	
1-Drilling Fluid	-Flow rate (velocity and flow regime) -Mud rheology and properties -Mud density -Mud type (WBM or OBM)
2-Cuttings	-Cutting size and shape -Cutting density and
3-Wellbore hole	-Annular/pipe eccentricity -Drillpipe rotation -Inclination angle -Rate of penetration ROP -Hole size

Table 4.1: Factors that effect hole cleaning performance

The impact of the drilling fluid on the effective cuttings transport is a major role to avoid accumulating cuttings bed in the wellbore annulus. The impact on the hole-cleaning impact can be illustrated as follows:

1. Drilling fluid Flow Rate:

The flow rate of drilling fluid is the most critical parameter that significantly impacts hole-cleaning performance. Increasing the flow rate causes an increase in fluid velocity in the annulus, which improves cutting transport and reduces cuttings-bed area in the annulus. ECD can be increased in high fluid flow rate, taking into consideration that which might induce fracture in the wellbore. Therefore, a balance between well stability and cutting transport, with the appropriate flow rate adjusted is required during the drilling operations. [4][46]. See figure [4.7]

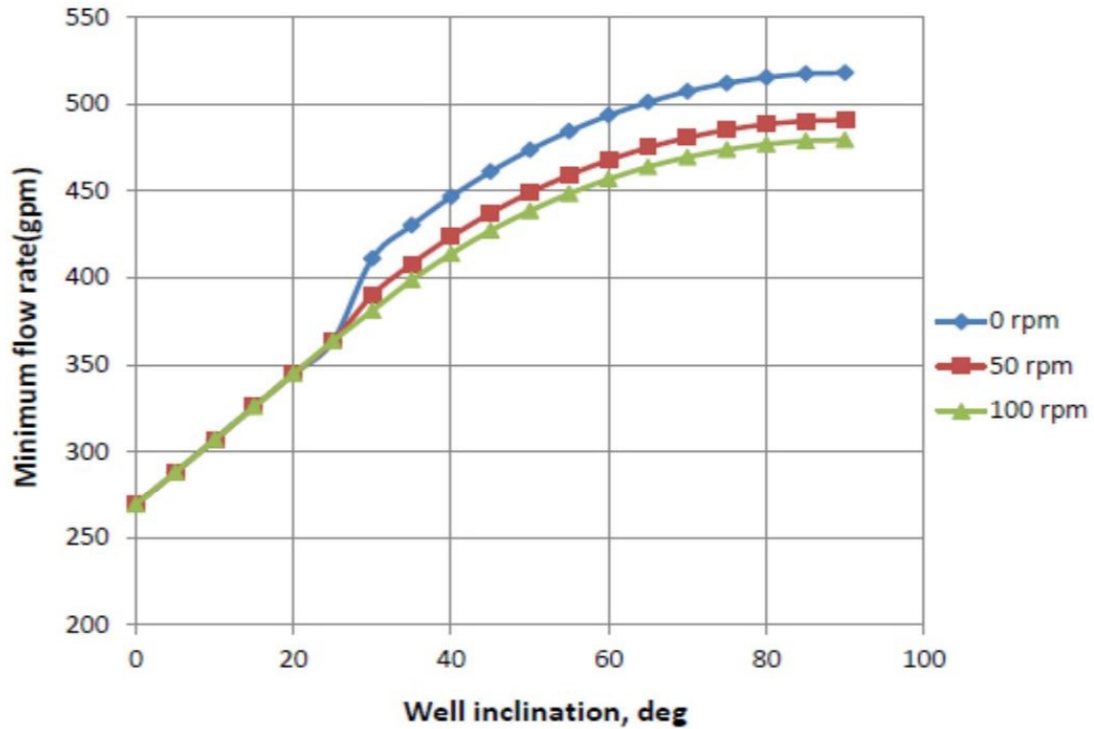


Figure 4.7: Effect of Flow Rate (RPM) on cutting transport

2. Drilling fluid rheology and properties:

An important function, 'carrying-capacity of drilling mud', can be defined as an ability of fluid to transport cuttings, it can also be defined as cuttings lifting or hole-cleaning capacity. The drilling fluid rheology and properties have the following effects on the hole-cleaning process, depending on other criteria such as cuttings and wellbore hole:

- Increasing plastic viscosity to yield stress ratio decreases the carrying capacity and increases the requirements of minimum flow rate [4]. See figure [4.8]

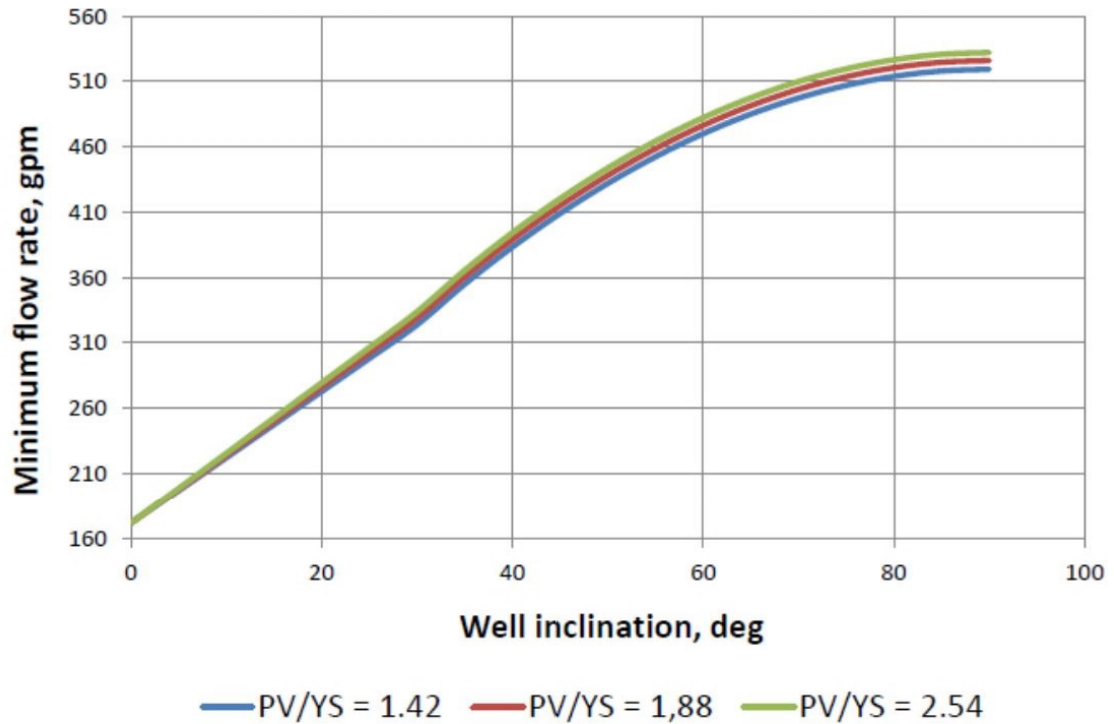


Figure 4.8: Effect of mud PV/YS ratio of drilling fluids on Carrying Capacity

- Increasing yield point, apparent viscosity and initial gel strength can improve carry capacity and reduce the cutting-beds concentration in the concentric annulus. This effect is significant in low and medium annular velocities and insignificant in high velocities.[44]
- Fluid rheology effect depends on the size of the cuttings(the transport efficiency of small cuttings comparing to the transport efficiency of the large cuttings) [21]. See figure[4.9] that illustrates the combined effects of Rheology and RPM on Carrying Capacity and cutting transport.

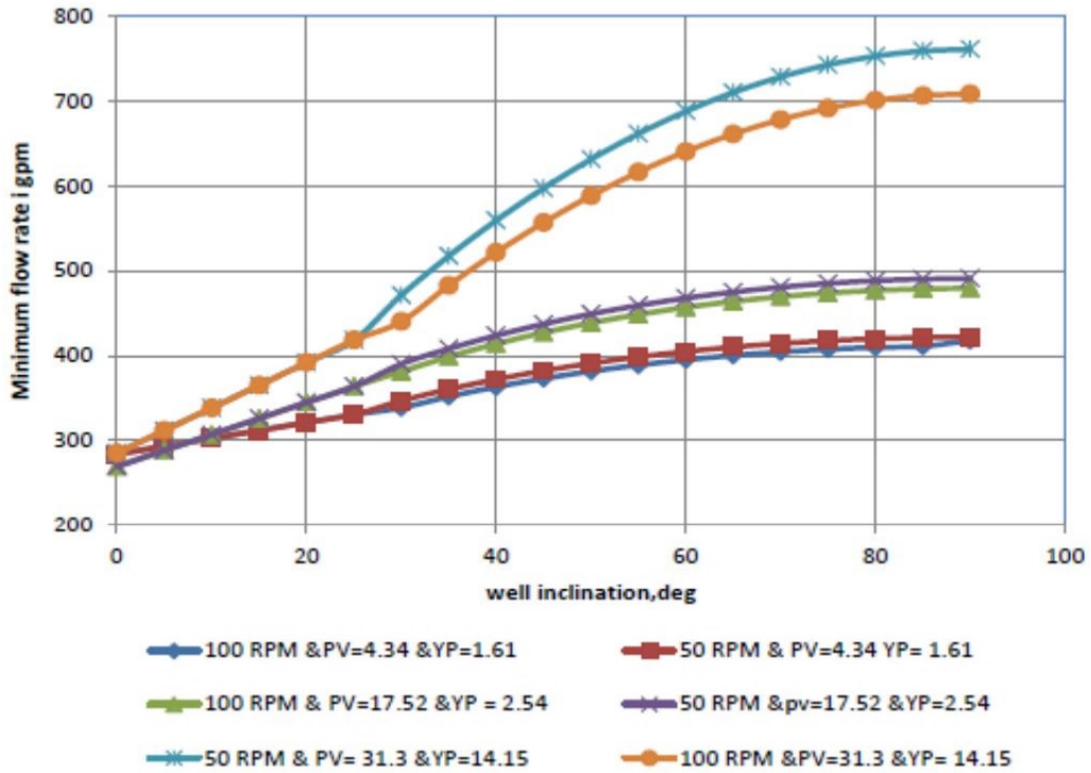


Figure 4.9: Effect of combined effects (RPM) and rheological properties on cutting transport

- Drilling fluid with low viscosity is more effective than the drilling fluid with high viscosity when using the same flow rate.

3. Drilling fluid density:

- Increasing mud weight has an impact on improving cutting transport through decreasing cuttings-bed area [65][4]. See figure[4.10]

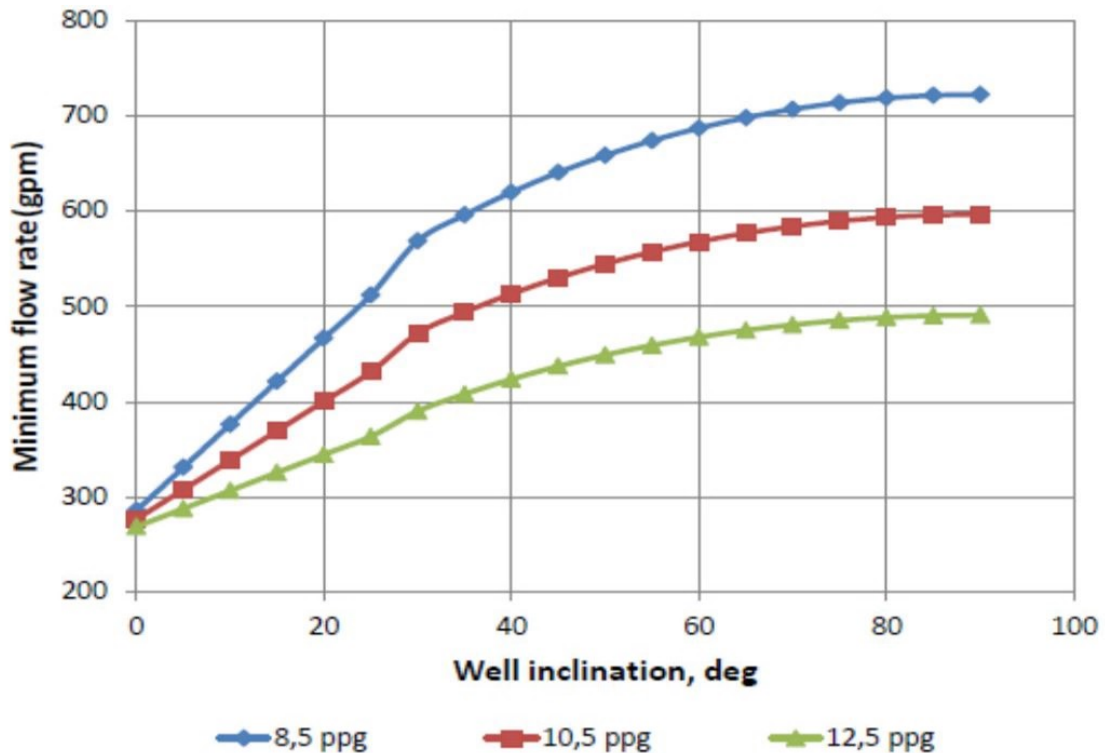


Figure 4.10: Mud density effect on cutting transport

4. Drilling fluid types:

- Using WBM during drilling an inclined well with inclination angle from (40-50) degree is better in hole cleaning than OBM. [39]
- At a high inclination angle, the required torque for cutting transport and reducing the cuttings-bed area in WBM is lower than OBM, whilst at the lower inclinations angle between 0° to 50° degrees, the required torque is lower while using OBM at the same annular cuttings concentrations.[39]
- Low yield stress and low API gel can be considered factors to optimize the hole cleaning process. Using WBM in drilling can lead to a hole-cleaning problem in that water can react with the cuttings and form a gel formation, whilst OBM can be used to minimize the gel formation in the cuttings bed.[61]

The figures of factors on hole-cleaning are taken from curriculum PET-580/Advanced Drilling Engineering and Technology [4].

Drilling fluid characteristics, particularly drilling fluid density, play as a significant role in achieving the needed bottomhole pressure as utilizing the MPD methods in drilling operations.

The combination of drilling fluid density, backpressure, and the MPD technique will be explored further in Chapter 6.

Inappropriate drilling fluid properties can be one of the major causes of incidents in the wellbore such as kick, lost circulation, and pack off, which will be addressed more in chapter 5.

Chapter 5

Narrow Pressure Margin Wells

5.1 Narrow Pressure Margin Well

Definition

The wellbore is subjected to several types of pressures based on the geopressure profile which can be used to determine the pressure margin. To better understand the narrow pressure margin, it is necessary to identify the two most influential types of pressures encountered throughout the drilling operation, which are characterized as follows:

- Pore pressure, which represents the fluid pressure within pores of the drilled formation during drilling operations.
- Fracture pressure which causes the fracturing of this formation.

The narrow pressure margin well is defined as a situation in which the pore pressure is too close to the fracture pressure, that can provide significant potential problems, complicate drilling operations, and expose the well to several incidents throughout the drilling process.

In order to overcome the possible incidents caused by this phenomena (narrow pressure margin well), the appropriate solutions must be found by observing the wellbore stability status. Recently, the automated drilling system has been employed to monitor narrow pressure margin wells and manage bottomhole pressure to maintain the wellbore in safe mode.

Narrow pressure margin wells with narrow operations windows are common in deep-water wells due to the low overburden gradient in the deep water, resulting in low fracture pressure, which is a function of overburden and pore pressure [15]. Likewise, the brownfields or so-called the mature field (The field after a certain period of production, or the fields with declining production status [9]), are suffering from pressure depletion (drop-in average pore pressure) due to reduction of the volume of the hydrocarbon in the reservoir results in drilling fluid losing thus lost circulation. The high-pressure high temperature (HPHT) wells are also susceptible to complicated drilling operations, due to the narrow pressure margin. [37]

The figure [5.1] illustrates the difference between a safe operating window in a shallow water well and a deepwater well with a narrow pressure margin due to the low overburden gradient and fracturing gradient. [28].

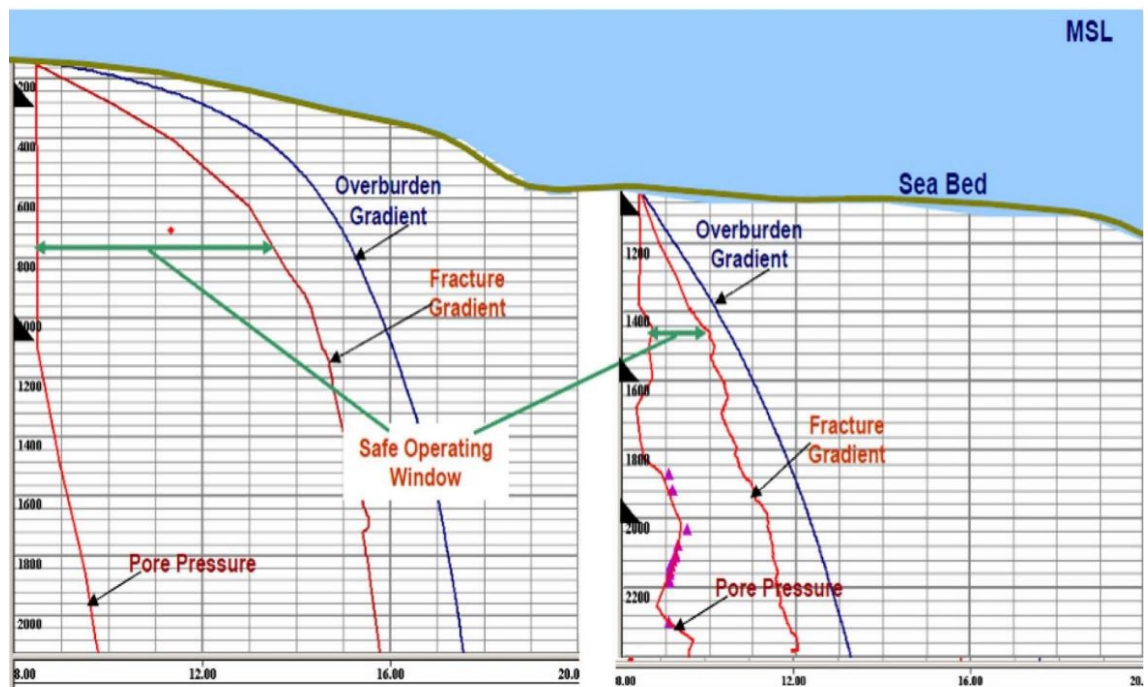


Figure 5.1: DeepWater and Shallow wells with operating margin and fracture gradient

5.2 Potential Incidents in Narrow pressure margin well

Several incidents may occur in a narrow pressure margin wells are outlined below as follows:

5.2.1 Formations Influx

What is formation influx?

Formation influx, also known as a Kick incident, is one of the most concerning issues in the oil and gas industry due to the enormous costs associated with controlling the BHP, and the hazard that can occur to humans, material and environment during kick occurrence.

The formation influx is typical at the narrow margin wells since the operation margin between pore pressure and fracture pressure is quite narrow.

Kick is the flow of formation fluid into the wellbore during the drilling operation. The reason for occurrence of kick into the wellbore, is that the pore pressure increases over the bottomhole pressure.

What can cause the kick?

The main reasons can cause kick incident are as follows[36]:

1. Light mud weight:

In this case, the hydrostatic pressure which is exerted on the formations will be decreased, leading to the lower BHP less than the pore pressure resulting in the flow of the formation fluid into the wellbore.

This situation may occur as a result of selecting an improper drilling fluid density when starting the drilling process.

2. High formation pressure:

Overburden pressure or pore pressure rises over what was anticipated.

3. Tripping, snubbing operations:

The wellbore has been insufficiently filled with drilling fluid due to the motion of the drillstring, resulting in a drop in hydrostatic pressure.

4. swabbing in drilling operation:

Bottomhole pressure is reduced as a result of swabbing drilling fluid out of the wellbore during pulling up the casing, bottomhole assembly (BHA), and logging tools.

5. Lost circulation:

Lost circulation, also known as mud loss, results in an insufficiently filled wellbore with drilling fluid, lowering the hydrostatic pressure in the well.

5.2.2 Lost circulation

What is Lost circulation

Lost circulation is one of the catastrophic scenarios that might be regarded a severe concern during drilling operations.

During drilling operations, drilling fluid is pumped through the drillstring in the wellbore, and for a variety of reasons, lost circulation occurs, remaining the wellbore unfilled with drilling fluid when it returns from the bit up to the surface through the annulus between formation and drillstring. During lost circulation incidents, the mud flow rate out is reduced in compared to the flow rate in ($Q_{out} < Q_{in}$), and the volume of drilling fluid exiting the well is less than the volume of drilling fluid entering the wellbore ($V_{out} < V_{in}$).

Drilling fluid loss is a function of (Q_{in} , Q_{out}) and (V_{in} , V_{out}), and it can be addressed by preventive tests such as the LeakOff Test (LOT) and the Formation Integrity Test (FIT).[14][16]

What are main reasons behind lost circulation incidents?

Several causes behind the lost circulation incidents are listed below as follows [16] [42]:

1. Heavy mud weight

Using a heavy mud weight during drilling operations can lead to an increase in the pressure of the wellbore downhole, which is exerted on the formation due to increasing friction pressure, resulting in fracture induce, thus losing drilling fluid and lost circulation scenario.

2. Natural fractures and unconsolidated formation

Fracturing can be happened particularly during drilling the narrow pressure margin wells with weak natural formations or unconsolidated formations, which can not withstand the exerted pumping pressure on these formations, resulting in losing drilling fluid to the formation or thief zone.

3. Cavernous formations

Cavernous formations are the most formations prone to the lost circulation incidents due to high permeability, such as limestone, which are also known as more challenging to seal.

Figure [5.2] illustrates the kick and lost circulation induces

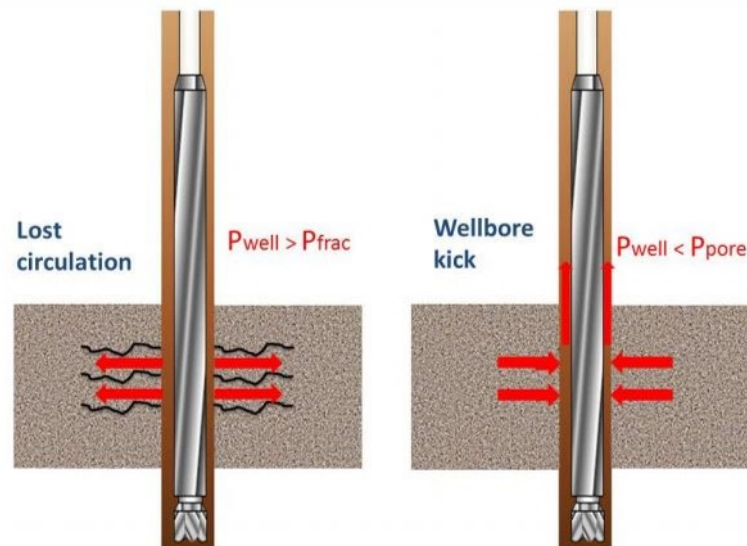


Figure 5.2: kick and lost circulation ((www.drilling-mud.org))

5.2.3 Pack off

Definition

The solids and cuttings formed and accumulated during penetrating and drilling the formations would build a plug that prevents the drillstring from circulating, thereby partially or wholly blocking circulation flow in the wellbore, this is also known as pack-off incident in the wellbore. see figure [5.3].

The most catastrophic event induced by the pack off incident in the drilling system is a stuck pipe, which can result in significant expenditures to free the drillstring from the formed plug into the wellbore, and increasing non-production time (NPT) [78]

Main reasons cause pack-off incident

Along with hole geometry and differential sticking, pack-off is one of the causes of stuck pipe. The reasons for the pack-off event are as follows [13]:

1. Poor hole cleaning

According to Chapter 4 "Drilling Properties," choosing the inappropriate drilling fluid properties results in inadequate hole cleaning and insufficient cutting transport, which causes pack off induce, thus stuck pipes problem owing to accumulated cuttings in the annulus surrounding the drilling pipes.

2. Wellbore instability

Drilling the cavernous formation might cause pack-off owing to the entry of caving portions into the wellbore or collapse and form a plug that partially or wholly brakes drillstring movement.

One of the essential issues during hole cleaning and pack off incident is calculating the volume of the generated cuttings during drilling. The following formula is used to determine the volume of the cuttings entering the wellbore [62]:

$$V_c = \frac{(1 - \emptyset) \times D^2 \times ROP}{1029.4} \quad (5.1)$$

Where:

- V_c : Cuttings volume bbl/hour
- \emptyset : Porosity of formation %
- D : wellbore diameter inch
- ROP : Rate of penetration ft in hour

The volume of cuttings can be calculated in another unit as follows :

$$V_c = \frac{(1 - \emptyset) \times D^2 \times ROP}{24.49} \quad (5.2)$$

Where (V_c) is a volume of the cuttings in gallon/hour

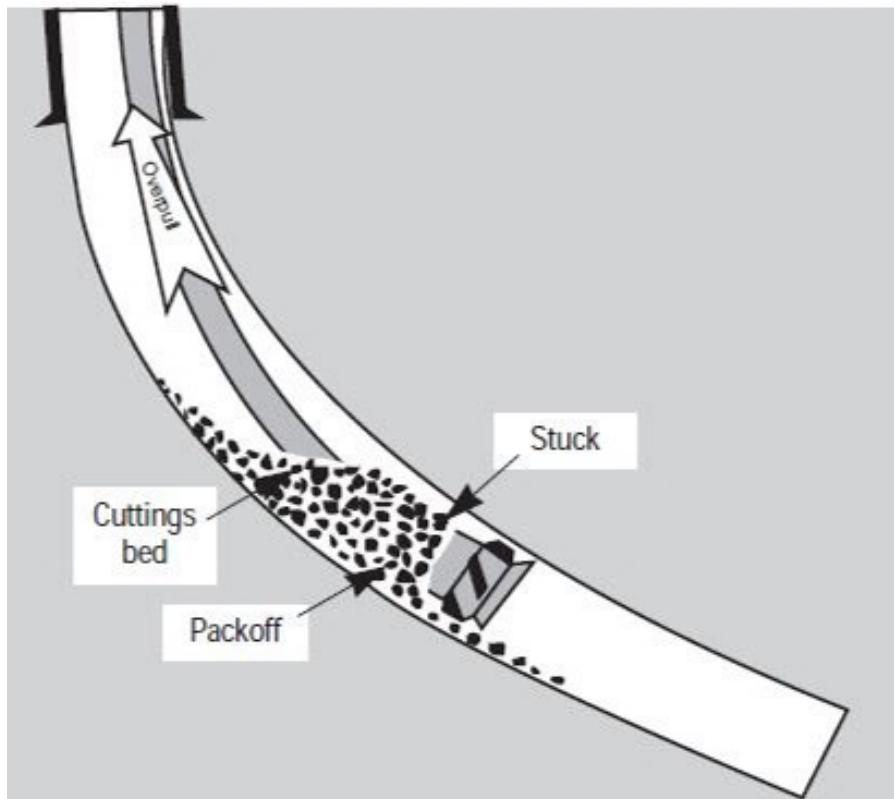


Figure 5.3: Pack off incident(www.drillingcourse.com)

It has been approached the knowledge, in this master thesis, about many major drilling issues and challenges that occur during complicated drilling operations in narrow pressure margin wells. This knowledge can contribute to obtain the optimization of drilling operations using various techniques and methods, such as the managed pressure drilling (MPD) methodology and choosing the proper drilling fluid properties, in order to achieve optimal results.

5.3 Managing the narrow pressure margin wells

The primary issue in deepwater wells, mature/brownfield wells, HPHT wells, and wellbores when the well-bound is susceptible to varying downhole pressures, as illustrated in figure [5.4] , is bottomhole pressure or annular pressure control, owing to the narrow pressure margin and complicated drilling operations in such wells. Therefore, the "accuracy" and high "sensitivity" in drilling operations are the central demands in such wells to maintain the control of the bottomhole pressure, which is a function of hydrostatic pressure, between pore pressure and fracture pressure. See figure [5.5].

Downhole Pressures

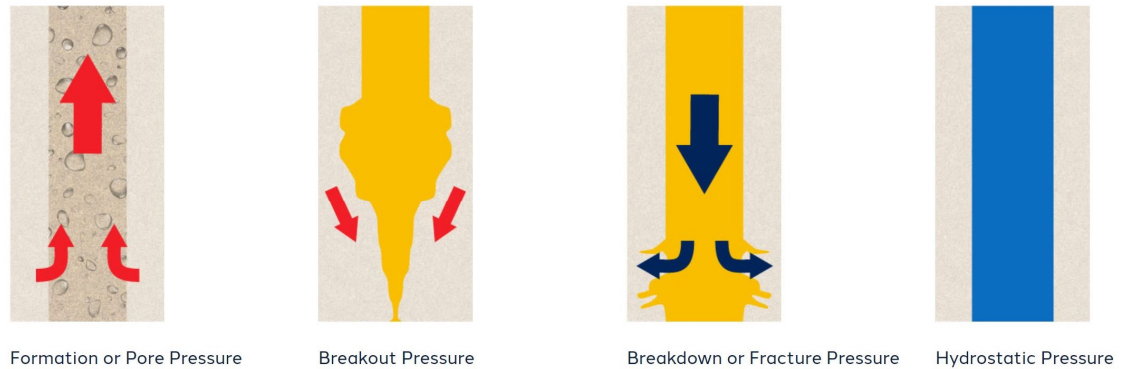


Figure 5.4: Downhole Pressures(<https://www.beyondenergy.ca/mpd-101/>)

Innovation and technological development in the oil and gas industry was crucial in light of the complicated drilling operations in such wells. Hence, the introduction of automation into the drilling process was the main option to avoiding conventional drilling challenges such as kick, lost circulation, and pack off, hence lowering drilling operations expenses.

Based on monitoring the drilling system's behavior, analyzing the acquired data, and developing a model to design a drilling well plan profile, the driller may make an informed choice to avoid drilling incidents.

Early detection of the kick is a great illustration of how automation may well be introduced. Monitoring fluid behavior in the wellbore, predicting and developing a suitable model help select an optimal drilling fluid, proper flow rate, and suitable drilling method, such as the MPD drilling method to detect the kick.

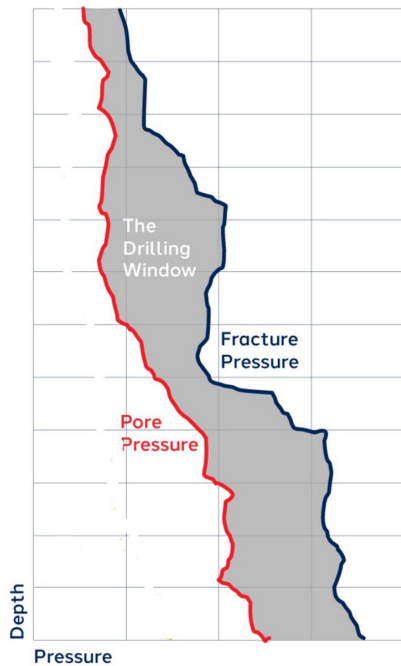


Figure 5.5: Drilling Window (<https://www.beyondenergy.ca/mpd-101/>)

Managed Pressure Drilling (MPD) is one of the most crucial methodology and the primary technical process which is used to precisely control the annular pressure profile throughout the wellbore in the narrow pressure margin wells.

In addition to effectively employing the MPD technique to control pressure in the downhole of narrow pressure margin wells, optimizing drilling fluid properties has a significant impact on annular pressure control and wellbore stability.

Chapter 6

Managed Pressure Drilling (MPD)

6.1 Introduction

Due to high drilling costs and increased non-productive time (NPT), oil and gas companies sought to improve drilling methods and focus on pressure at the downhole, particularly when drilling wells with narrow pressure margins. As a result, the MPD approach was created in order to precisely adjust the bottomhole pressure by maintaining the BHP between pore pressure and fracture pressure, thus mitigating the well incidents.

The non-productive time (NPT) that costs oil and gas companies enormous expenses can be categorized as follows [24]:

- Rig repairs
- BottomHole Pressure BHP problems
- Well incidents during drilling activities, i.e. stuck pipe, kick, lost circulation. etc
- Failure in Subsea equipment
- Failure in surface equipment
- Failure in Bottomhole assembly BHA
- Weather factor
- Human errors
- Waiting time, unplanned issues

The MPD method is regarded as a primary key to achieving well integrity and mitigating uncertain well incidents such as kick, lost circulation, and differential pressure sticking, particularly when drilling wells with narrow pressure margins such as depleted reservoirs, high-pressure, high-temperature, deepwater, and extended-reach wells. See figure [6.1], which is taken from [4].

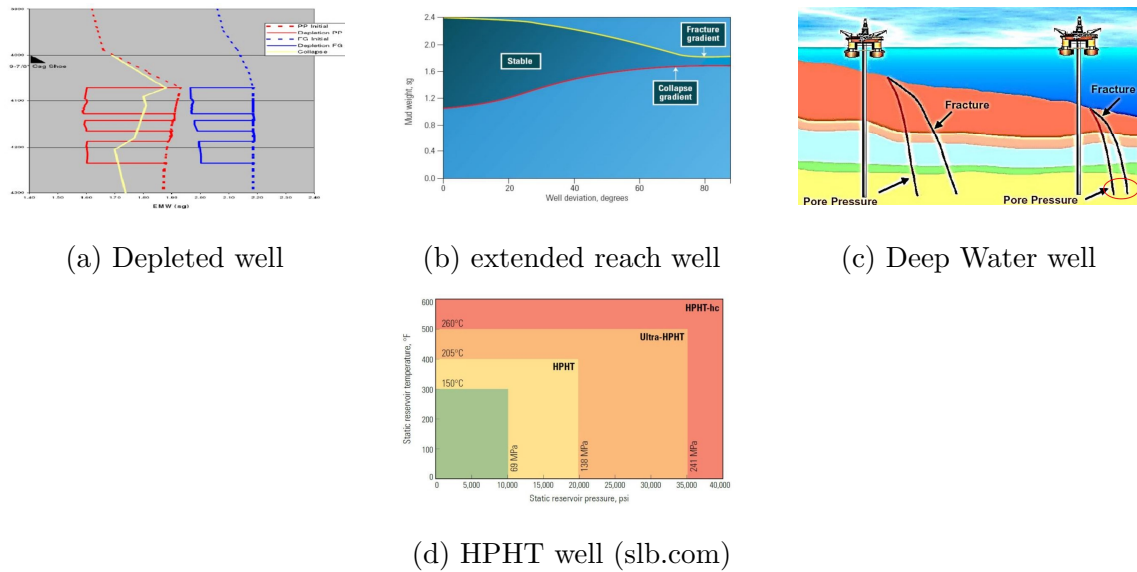


Figure 6.1: MPD application zones

6.1.1 Definition of MPD

According to the International Association of Drilling Contractors (IADC, 2014) (IADC/URL), MPD is defined as “an adaptive drilling process used to precisely control the annular pressure profile throughout the wellbore. The objectives are to ascertain the downhole pressure environment limits and to manage the annular hydraulic pressure profile accordingly. It is the intention of MPD to avoid the continuous influx of formation fluids to the surface. Any influx incidental to the operation will be safely contained using an appropriate process”.

6.1.2 The basic techniques and applications of MPD

MPD method is classified into three basic applications as follows:

1. Pressurized Mud Cap Drilling (PMCD) :

PMCD is one of the MPD variants that enables continuing the drilling within minimizing the NPT and mitigating the drilling fluid losses owing to total loss circulation.

In order to accomplish a successful PMCD method, a Rotating Circulating Device (RCD) is used to seal the annulus.[19]

2. Dual Gradient Drilling (DGD):

Dual Gradient Drilling (DGD) is a drilling method used to overcome deepwater well problems and wells with a narrow pressure margin. Two fluid column gradients were employed during the drilling of DGD method: one is a seawater gradient from the rig floor to the mudline, and the other is a heavier mud gradient from the mudline to the target depth.[20]

3. Constant Bottom Hole Pressure(CBHP):

The major goal of utilizing this approach is to maintain the bottomhole pressure constant and avoid ECD variations while providing surface backpressure, which allows the drilling to continue with fewer possible drilling incidents.[7]

Table [6.1] below illustrates the differences in the objective of MPD applications: [43]

MPD variant	CBHP	DGD	PMCD
Unknown drilling window	✓	×	×
Slow ROP	✓	×	×
Severe loss of circulation	×	×	✓
Sour formation	×	×	✓
Avoid gross overbalance	×	✓	×
Ballooning problem	✓	×	×
Well control risk	✓	×	×

✓ = yes × = no

Table 6.1: Objectives of MPD techniques

6.1.3 MPD Equipment System

Figure [6.2] shows the main Beyond MPD equipment set-up (BeyondEnergy MPD) as follows:

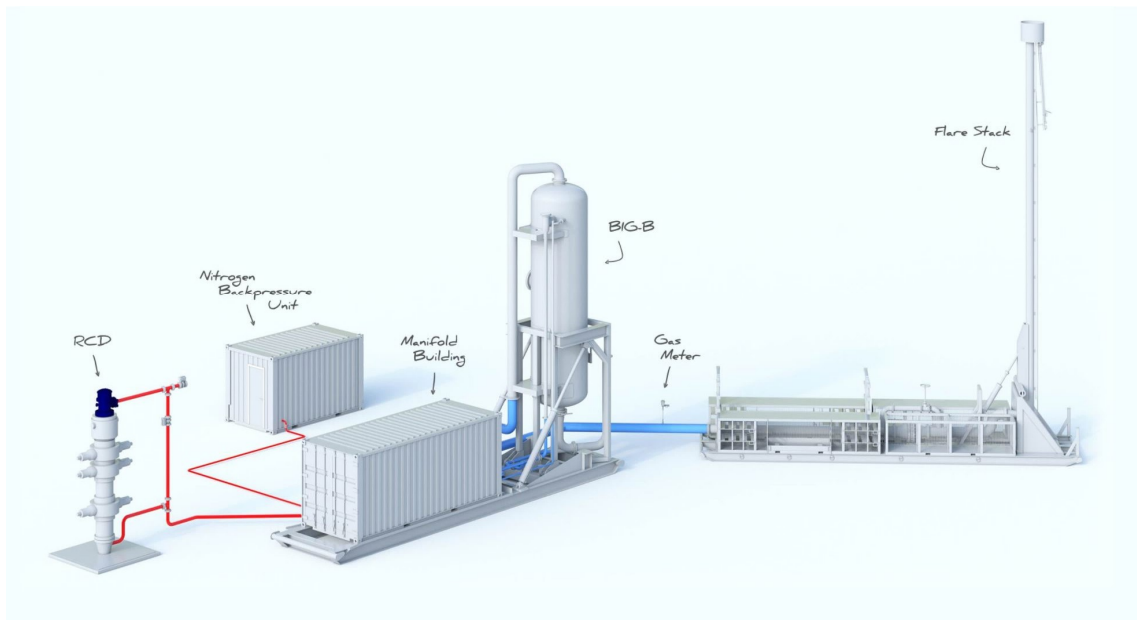


Figure 6.2: MPD System components
<https://www.beyondenergy.ca/mpd/>

- Rotating Control Devices (RCDs)

- Nitrogen BackPressure Unit
- MPD Integrated Manifold Building which includes:
 - Automated BackPressure Control System
 - MPD Choke
 - Pressure Relief Valves (PRV)
 - Coriolis Flow Meter
- Integrated Gas Buster Separator (BIG-B)
- Flare Stack
- Micro flux control system

A diagram of a simplified MPD System for deepwater application is shown in figure [6.3], which illustrates the Weatherford MPD system [74].

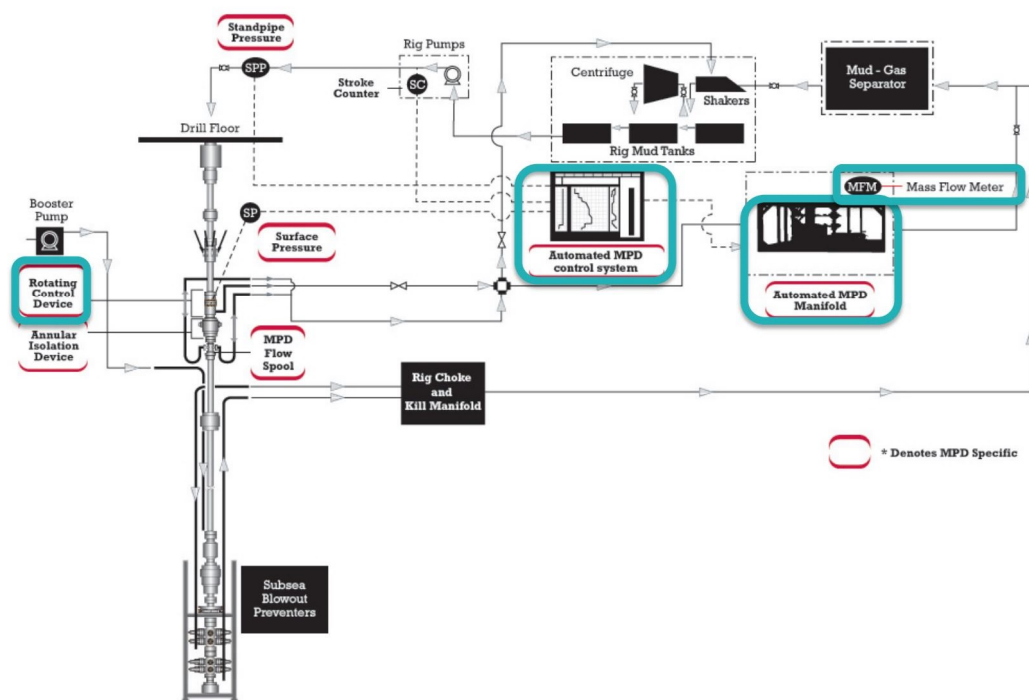


Figure 6.3: MPD System Diagram [Weatherford,2015]

6.2 MPD, UBD and OBD methods

MPD methodology has been developed to effectively mitigate uncertain challenges and accomplish successful drilling operations in wells with narrow margin hole sections.

In contrast to conventional drilling methods, the MPD drilling technique utilizes a closed circulating system during drilling instead of an open circulating system to

the atmosphere at the surface.

Figure [6.4] shows the pressure profile windows in Managed Pressure Drilling, UnderBalanced Drilling (UBD), and OverBalanced Drilling (OBD) zones.

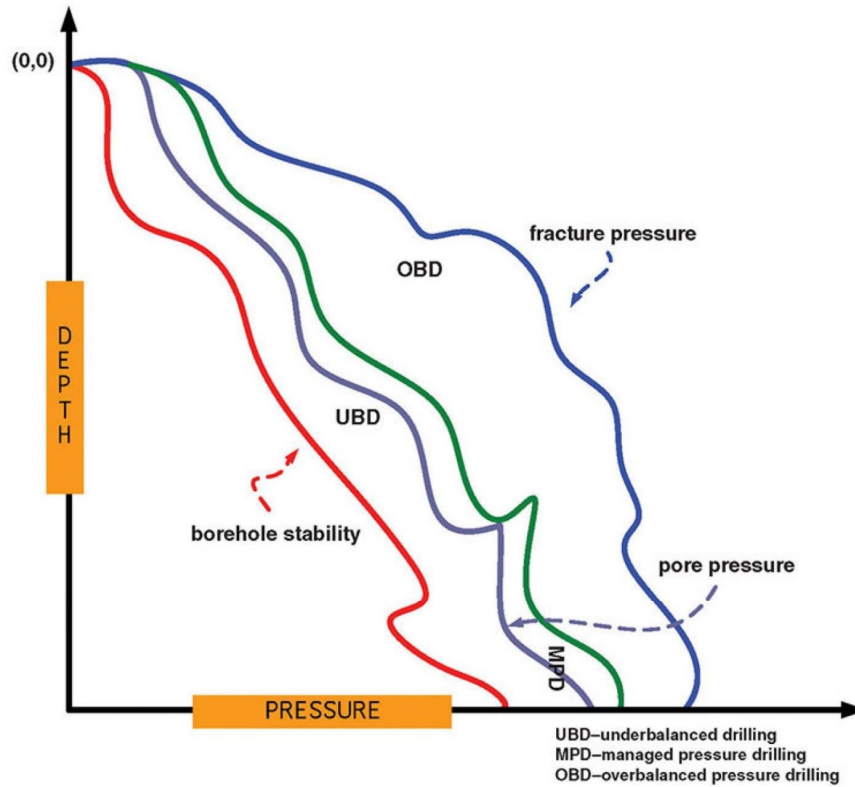


Figure 6.4: Pressure profile window(JPT.org)

6.2.1 Managed Pressure Drilling and Under Balanced Drilling

Under Balanced Drilling method is similar to the MPD method in many stations, in which both methods depend on the closed circulating system, and the UBD method uses many of the MPD tools and equipment during drilling operations.

The UBD drilling method employs more separation units than the MPD technique, allowing for continuous drilling while maintaining controlled production.

A light mud column is utilized in the UBD method to prevent damage to the formation, which might be fractured at high mud density where:

$$P_{reservoir} > P_{bottomhole} = P_{hydrostatic} + P_{friction} + P_{choke} \quad (6.1)$$

This demonstrates that the wellbore is vulnerable to formation influx and kick occurrence [26]. Whereas the MPD approach maintains bottomhole pressure between pore pressure and fracture pressure, avoiding drilling accidents that are associated to non-productive time (NPT) [63] as shown in figure [6.4]

6.2.2 Managed Pressure Drilling and Over Balanced Drilling

The MPD approach has been used to deal with drilling issues that arise when using conventional methods.

The BHP in the conventional drilling method can be determined as follows [17][43]:

During Drilling:

$$P_{reservoir} < P_{Bottomhole} = P_{Hydrostatic} + P_{friction} \quad (6.2)$$

In Static condition:

$$P_{reservoir} < P_{Bottomhole} = P_{Hydrostatic} \quad (6.3)$$

In the MPD approach, a surface backpressure pump is employed to keep the BHP in a balanced state. where [17][43]:

During Drilling :

$$P_{reservoir} \cong P_{Bottomhole} = P_{Hydrostatic} + P_{friction} + P_{backpressure} \quad (6.4)$$

In Static condition:

$$P_{reservoir} \cong P_{Bottomhole} = P_{Hydrostatic} + P_{backpressure}$$

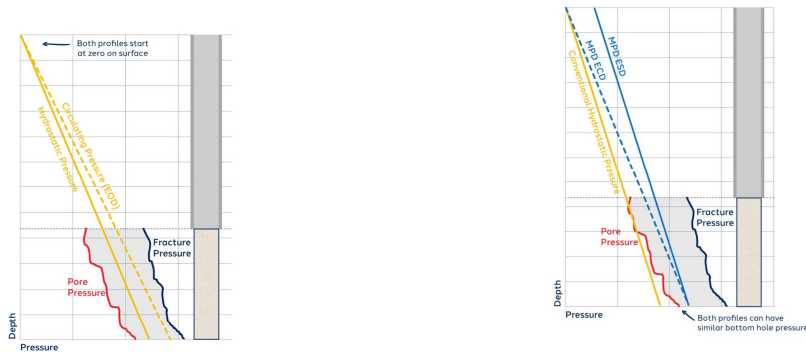
(6.5)

-In conventional drilling, the drilling's circulating system is open to the atmosphere whilst it is closed in the MPD method.

The pressure profile at the surface and in the well's downhole could be used to address the limitations of an open circulating system. The pressure profile of an open circulating system always starts at zero at the surface (where it connects to the atmosphere), and the pressure in the well's downhole fluctuates due to added pressure during pumping and drops when the pump is turned off.

Therefore, MPD application has been employed to adjust the downhole pressure by manipulating the annular pressure.

Figure [6.5] illustrates the difference between conventional drilling with hydrostatic pressure profile and pressure profile during pumping and circulating drilling fluid. The figure [6.5b] also shows that the MPD pressure profiles with no zero starting as conventional method and how the pressure profile is adjusted to maintain ECD and downhole pressure in a safe window after the drop in bottomhole pressure lower than formation pressure [25],[76].



(a) Conventional pressures profile

(b) MPD method intervention

Figure 6.5: Difference between MPD and Conventional Drilling

- During pipe connection in conventional methods, the driller will suspend pumping drilling fluid and circulation process to achieve tripping pipe, which can lead to loss of drilling fluid and encounter a failure that can be controlled by employing MPD approach. The use of a backpressure pump is required to achieve a constant bottomhole pressure and compensate for the drop in BHP, that must be maintained higher than formation pore pressure, while taking fracture pressure into consideration.

When using Conventional drilling method:

- The BHP during circulation and the pump is on can be calculated as follows :
Q = on

$$BHP = \Delta P_{Hydrostatic} + \Delta P_{Annularloss} \quad (6.6)$$

Moreover, the ECD and BHP is between pore pressure and fracture pressure.

- During connection and drillstring tripping, the pump is turned off. Hence, the frictional force generated by fluid movement will cease, resulting in the annular pressure loss vanishing.

Where (Q = 0) and ($\Delta P_{Annularloss} = 0$)

$$\Delta P_{Annularloss} = \frac{f \cdot L \cdot \rho \cdot v^2}{2 \cdot D} \quad (6.7)$$

Where:

$$v = \frac{Q}{A} \quad (6.8)$$

Where: f = friction factor, L = length of pipe work (m), D = inner diameter of pipe work (m), v = velocity of fluid (m/s)

$$BHP = \Delta P_{Hydrostatic} \quad (6.9)$$

As a result, BHP is lowered, and there is a requirement to compensate for the reduction in downhole pressure in order to eliminate the chance of a kick occurrence and maintain the wellbore in a safe mode by employing the MPD technique.

When using MPD drilling method:

- BHP during circulation:

$$BHP = \Delta P_{Hydrostatic} + \Delta P_{Annularloss} + \Delta P_{back} \quad (6.10)$$

- During pipe connection :

$$(Q = 0) \text{ and } (\Delta P_{Annularloss} = 0)$$

$$BHP = \Delta P_{Hydrostatic} + \Delta P_{back} \quad (6.11)$$

The backpressure pump starts pumping while the choke valve begins to close during connection to increase BHP value and maintain BHP between formations pore pressure and fracture pressure. The MPD equipment system features an automated control system that maintains the BHP constant during pipe connection process, allowing the driller to complete the connection without losing circulation. [25],[67],[4], [47], [76].

Figure[6.6] shows The difference in BHP between Conventional and MPD methodology during tripping and pipe connection [38].

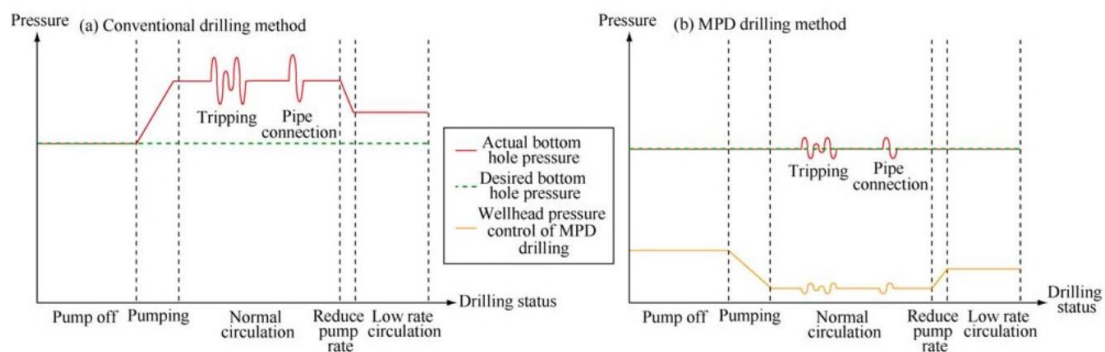


Figure 6.6: BHP in MPD and Conventional drilling method (Sciencedirect.com)

Figure[6.7] illustrates the using the Constant Bottom Hole pressure (CBHP) method to compensate the drop in annular frictional pressure (AFP) and equivalent circulating density by using backpressure pump and choke pressure in order to increase the AFP and control the BHP during pipe connection [4].

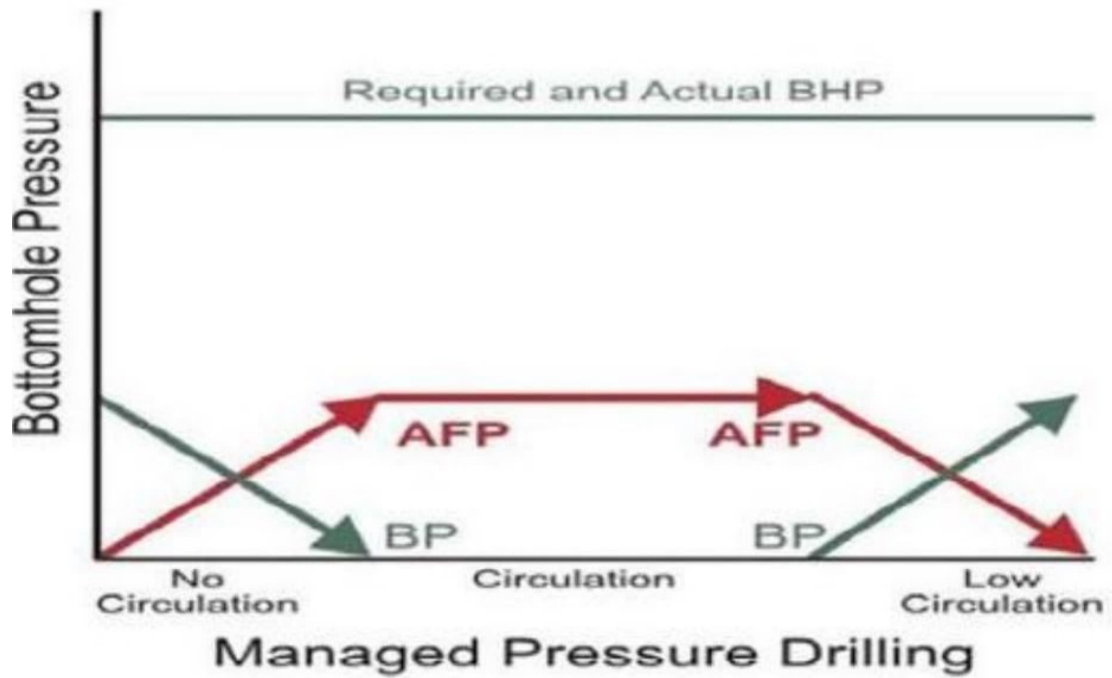


Figure 6.7: The usage of Back Pressure in CBHP Method

Figure[6.8] illustrates an example of the relationship between choke valve opening, choke pressure, BHP and flow rate. The figure illustrates the inverse proportionality between choke opening and choke pressure, where increasing choke pressure will increase the BHP. [51].

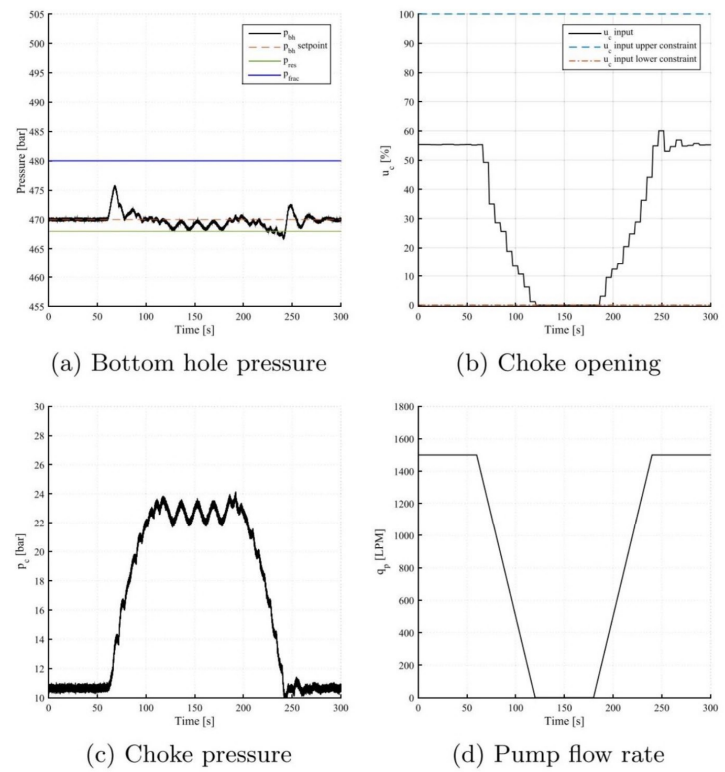


Figure 6.8: Bottom hole pressure tracking during pipe connection sequence

The table [6.2] below depicts the difference in wellbore control and well integrity while utilizing MPD and conventional methods. [43]

	Formation influx	Formation damage	Pressure related problem
Overbalanced drilling	√	×	×
Managed pressure drilling	√	√	√

× = no, √ = yes

Table 6.2: MPD vs Conventional method in well control

6.3 Managed Drilling Pressure advantages

All advantages of using MPD drilling method result in reducing drilling costs by reducing NPT.

Figure [6.9] illustrates that 40% of NPT during drilling operation in the Gulf of Mexico between 1993 and 2003 due to drilling problems that are pressure-related issues.

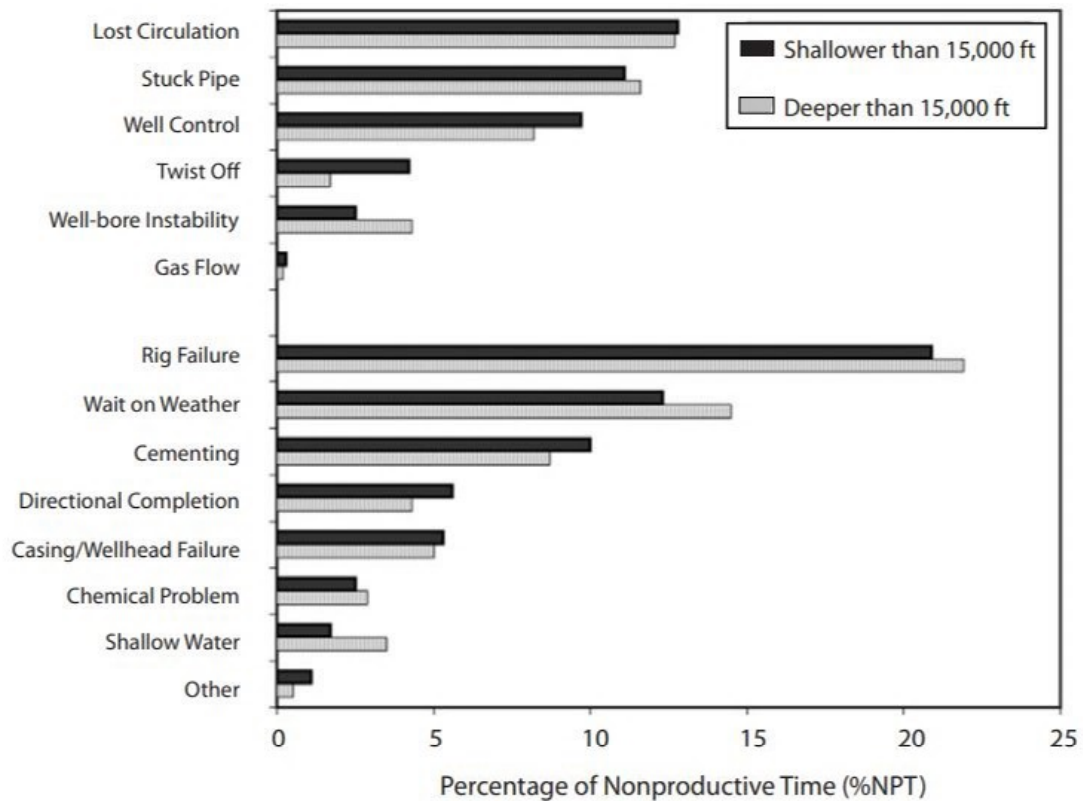


Figure 6.9: NPT in the Gulf of Mexico [60]

The main objective of the MPD methodology is to reduce NPT, thus reduce drilling costs. The advantages of using MPD are as follows [4],[60],[75] :

1. Reduce Non-productive time (NPT): Using of MPD method always aims to maintain the well borehole safety and mitigate the pressure control-related problems.
2. Reduce the number of required casing strings: Since casing is the solution to many drilling challenges, MPD approaches employ the casing point extending method.
In conventional drilling method, it is required (7) casing strings to reach the target, while it required only (3) casing strings to reach the same target
3. Improve Rate of penetration (ROP): Using MPD techniques help to enhance the drilling process and increasing the ROP
4. Reduce Lost Circulation and kick problem: MPD approach depends on maintaining BHP lower than fracture pressure and higher than pore pressure to avoid losing drilling fluid through the prone formation and preventing formation fluid influx into the wellbore.
5. Automatic kick circulation through choke line.
6. MPD manage the hazards and risks to the human’s health and safety and the environment

Utilizing MPD methodology may help oil and gas companies mitigate a variety of challenges during drilling operations while also enhancing drilling technology.

6.4 Managed Drilling Pressure disadvantages

The main challenges of using the MPD technique are as follows [4] :

- MPD method requires high quality and well experts
- complicated MPD operations as compared to conventional drilling methods
- MPD method still doesn't have any well-established standard

6.5 Summary

- The aim of using the MPD approach is to maintain the downhole pressure between pore pressure and fracture pressure constant in order to prevent drilling problems that might result in increased NPT and drilling expenses.
- The wells where MPD and UBD methods have been employed to overcome the challenges encountered during conventional drilling operations are as follows:
 1. Deepwater wells
 2. Extended reach wells (ERD)
 3. High-pressure high temperature wells (HP-HT) (Formation Temperature > 150 °C and Wellhead Pressure > 690bar)
 4. Depleted reservoirs
- MPD variants and applications are :
 1. Pressurized Mud Cap Drilling (PMCD)
 2. Dual Gradient Drilling (DGD)
 3. Constant Bottom Hole Pressure(CBHP)
- MPD method is utilized to reduce the drilling costs by reducing NPT, since using MPD method results in:
 - Reducing drilling problems because of pressure-related issues such as kick, lost circulation and differentially stuck drill pipe.
 - Reducing the number of casing strings
 - Improving the ROP

Chapter 7

Simulation Case Study

Introduction :

The process of developing a model of an existing and actual system in describing the features of the physical system's behavior and predict what will happen in the future is referred to as simulation. It enables a deeper knowledge of the system, which can then be utilized to regulate and replicate a process under artificial conditions that are comparable to natural ones.

Performing operations in the human's body requires the surgeon's training and getting knowledge about the components and functions of the human body. This can be obtained by training the medical student and teaching him/her, using the body of a doll which simulates the actual human body and know how to anatomy the human's body. It is the same when the carpenter intends to make something. He/She resorts to making a scale model that simulates the real purposed object and measures it, that can provide a safe work environment and optimal results. Hence, it was necessary to find a software that can run realistic simulations of the actual drilling operations, specially for wells with narrow pressure margin due to complicated drilling operations. The advantage of using a simulator is that experiments can be performed at low costs, high speed, repetitively, and without any safety issues. The OpenLab drilling simulator is a software that calculates and visualize virtual drilling operations, which it is a suitable simulator can be used for this project.

The OpenLab application is a web-based drilling simulator that has been developed at NORCE-Norwegian Research Centre. As a start of the simulation process, the OpenLab homepage can be used to explore the configuration and simulation options of the Case Study.

To create a configuration based on the Case Study, the user must choose the Rig and well template. By configuration option, the user can input his own configurations before running the simulation and customize the configuration by editing the Hole section (casing design), Wellpath (Survey stations), Drilling fluid properties (Rheology, Drilling fluid density and Drilling fluid type) for main fluid and reserve fluid, Drillsrting (Drillpipe, Bottom hole assembly and bit), Geology (Geopressure, Geothermal and Formation strength) and Rig (by editing the Rig equipment see figure [7.1]. Jill-Bit is used to assist the user in providing proper information when the inputs utilized are inappropriate for the configuration's option.

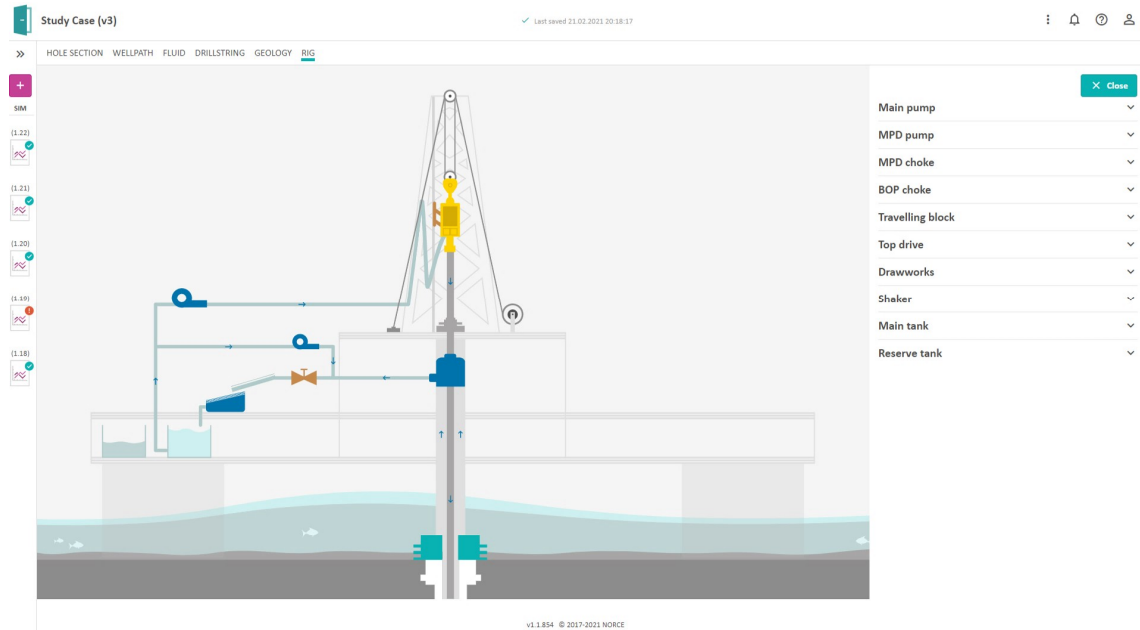


Figure 7.1: Configuration of Case Study

Simulations have a specific duration that can be run in various modes, such as the real-time mode, fast-forward and single steps. Based on imported pre-stored setpoints, the user can run the simulation in sequence mode and create future simulation setpoints.

Creating a new simulation requires the simulation's name and determination of the initial condition, model of configuration and drilling incidents.

In the left margin of the simulation sheet the drilling parameters can be controlled manually, and simulation mode can be chosen. The time graphs and depth graphs can be used to the simulation display, which help monitor the simulation during drilling operation. In terms of incident simulation and 3D virtualization, it can be customized more options.

After linking Matlab/Python and OpenLab, the simulation may be run using the Matlab or Python download packages and Matlab/Python login script, see figure [7.2].

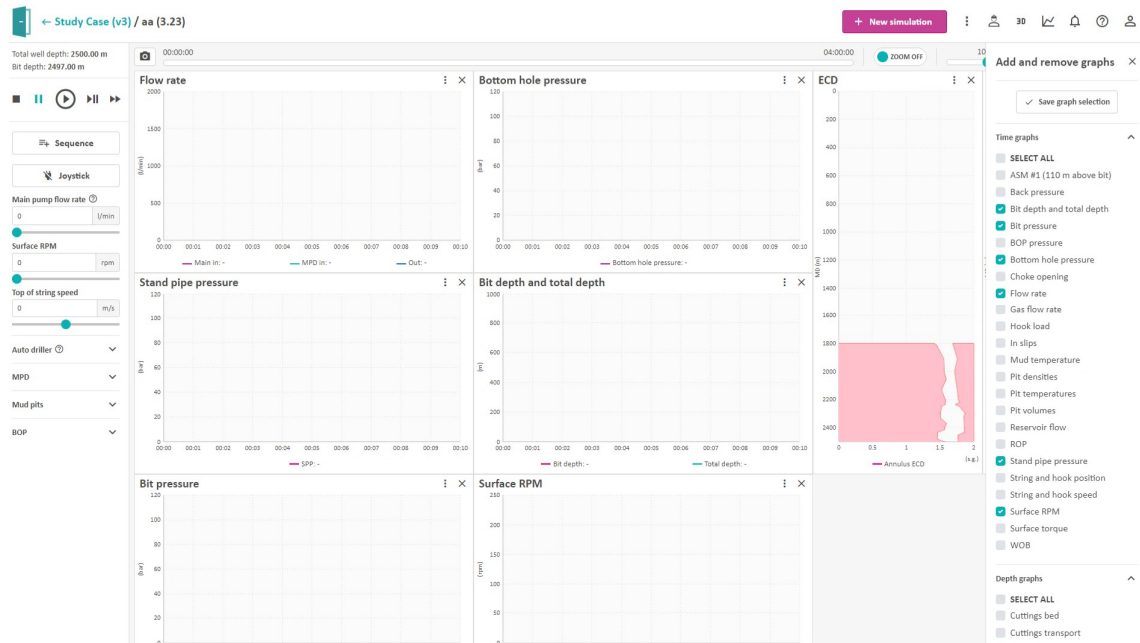


Figure 7.2: OpenLab Simulation

The Simulation of case study forms the basis of the workflow algorithm that is presented in Chapter 8. To address the objective of this thesis a case study has been created that simulates an operation in a narrow pressure margin well. Then, using MPD methodology and varied fluid density and rheology, simulations were carried out in order to prevent incidents such as kick, lost circulation, and hole-cleaning issues. The case study description is represented in tables provided in Appendix. The results of this project, that leads to the final workflow algorithm, is presented both in Chapter 7 and 8.

The work is divided into the following steps:

• Create downhole sections

To create a suitable openhole that can be used in simulations that fits with our objective, it is a demand to create an own configuration in OpenLab with a metric unit system. First of all, it has been created a configuration with the name "Case Study", and then edited the inputs in Holesection. "Case Study" openhole range in length from 1800 m to 2500 m, necessitating adjustments to the casing design and casing shoe locations as shown in figure [7.3].

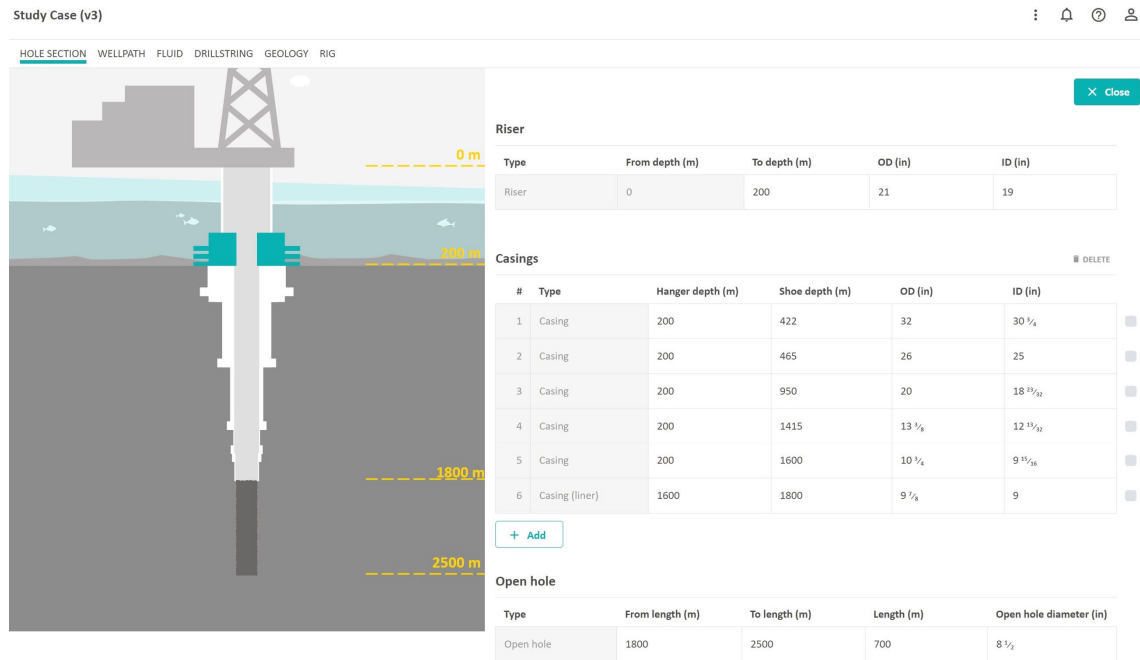


Figure 7.3: Hole Section

The Geopressures have then been edited by adjusting the pore pressure and fracture pressure based on True Vertical Depth (TVD) or Measured Depth (MD) to obtain a narrow pressure window suitable for the intended situation as shown in figure [A.6] without changing Geothermal and formation strength.

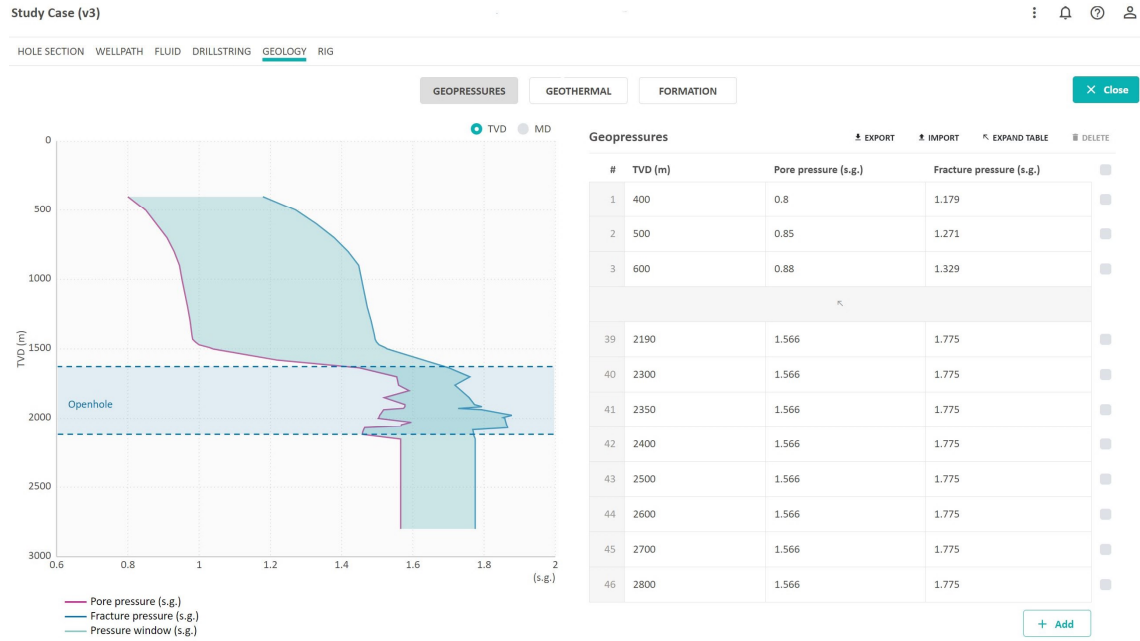


Figure 7.4: Geopressures

In terms of fluid properties, a starting value for drilling fluid density (1.55 sg.) with Generic OBM 1 type and Robertson-Stiff model in terms of rheology has been selected, as shown in the equation below, which represents the relationship between shear stress (lb/100ft²) and shear rate (rpm), see figure [7.5] : Robertson-Stiff model:

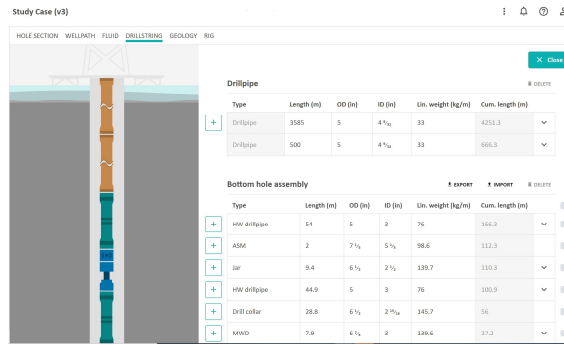
$$f(\zeta) = a(\zeta + c)^2 \tag{7.1}$$

Where a = 0.1039, b = 0.8438 and c = 60.8558.

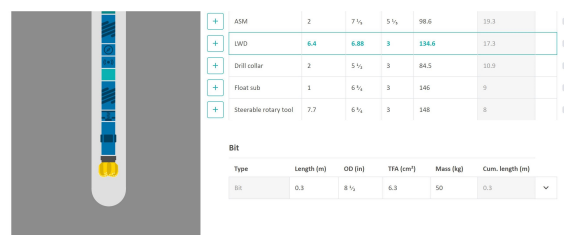


Figure 7.5: Fluid Properties

ASM components have been added to the drillstring's BottomHole Assembly (BHA) to acquire real-time measurements, as shown in the figure [7.6]. The other pre-programmed parameters in the Rig equipment and the Wellpath have been kept. The configuration is now ready to simulate and create an optimal algorithm.



(a) Drillstring 1



(b) Drillstring 2

Figure 7.6: Drill string includes BHA, Bit and Drillpipe components

• Running Simulation from OpenLab

1. Drilling with no influx and loss

Before drilling the wellbore, certain parameters must be provided.:

- The flow rate (l/min) should be enough for proper cutting transport and to prevent a cuttings bed from accumulating.
- Surface RPM (rpm) should be high enough to allow for good cutting transport while preventing cuttings bed accumulation.
- Top of string speed (Hook speed)(m/s) (+) for downward and (-) for (upward)
- ROP (m/h) or WOB (ton):

In this automation system, a PI controller was utilized, and the controller gains K_p and K_i are displayed when the WOB option is used.

- BOP is open
- The bit must be placed at the bottom by adjusting the Hook Speed (positive value is down, and negative value is up).

Bottomhole pressure (BHP) is the most important attribute that has to be observed during drilling to ensure the well integrity condition. Several factors influence the bottom hole pressure shown in the graphs during simulation. The factors which affect the BHP are as follows:

- (a) With a proper pump pressure, adequate RPM for cutting transfer, and a 100 % choke opening, density has an influence on BHP as illustrated below:

To raise BHP without using the MPD approach, and with 100 % choke opening and appropriate pump pressure for cutting transport, the density must be increased from the initial value of 1.55 sg.

The main reason for the well fracturing and a threat to the well integrity is that the bottom hole pressure becomes higher than fracture gradient pressure. Hence, the density has been lowered in order to avoid fracturing and keep the well safe. The density has been increased from initial value 1.55 sg to 1.78 to increase the BHP, which is offset by the fracturing event. Thus, the density has been reduced to achieve the desired BHP between pore pressure and fracture pressure.

The density impact on Equivalent Circulating Density, which can be expressed as an increase in density due to circulation, can be illustrated in the equation below.

$$ECD = \left[\frac{AnnularPressureLoss * 1000}{9.81 * TVD} \right] + MudWeight \quad (7.2)$$

The equation above shows that increasing density causes an increase in ECD, which should be between the pore pressure and fracture pressure to obtain well integrity.

Equation below illustrates the density impact on the hydrostatic pressure

$$HydrostaticPressure = \rho * g * TVD \quad (7.3)$$

BHP is controlled by hydrostatic pressure and circulating annular friction pressure during the drilling operation. Then the effects of density and Hydrostatic Pressure on BHP can be shown in below since:

$$BHP = Hydrostatic Pressure + Friction Gradient Pressure$$

Hence, increasing the density cause hydrostatic Pressure increasing which leads to an increase in the BHP and vice versa.

- (b) Choke opening effect on BHP without manipulating the drilling fluid density and with suitable pump pressure for cutting transport:

The choke opening affects the BHP and ECD as well. Depending on the initial mud density and suitable flow rate, which ensure adequate cuttings transport, it has been manipulated the choke opening to increase or decrease the BHP and ECD. Opening the choke gradually leads to increase BHP and ECD, whilst closing the choke causes a reduction in BHP and ECD .

- (c) The pump pressure is also an effective factor that has a major impact on the bottomhole pressure. The bottomhole pressure can be reduced

by reducing the pump pressure, and increasing BHP can be obtained by increasing the pump pressure.

- (d) Utilizing the backpump pressure in MPD system allows to adjust BHP and ECD, and help maintain the pressure at the downhole in safe margin, where

$$\text{BHP} = \text{Hydrostatic Pressure} + \text{Friction Gradient Pressure} + \text{Back Pressure}$$



Figure 7.7: Drilling with no influx or loss display

Time (hh:mm:ss)	Flow rate (l/min)	Velocity (m/s)	Auto driller	WOB (kN)	ROP (m/h)	RPM (rpm)	Choke open (%)	Choke flow rate (l/min)	BOP	Active pH	Return pH	Control active pH	Active pH density (g/cc)	Active pH temperature (°C)
00:00:01	2550	0.196	ROP	0	100	111	100	0	OPEN	MAINT	MAINT	ON	1.55	20
00:05:34	2550	0.196	ROP	0	100	111	100	0	OPEN	MAINT	MAINT	ON	1.57	20
00:05:37	2550	0.196	ROP	0	100	111	100	0	OPEN	MAINT	MAINT	ON	1.58	20
00:07:32	2450	0.196	ROP	0	100	111	100	0	OPEN	MAINT	MAINT	ON	1.58	20
00:07:34	2300	0.196	ROP	0	100	111	100	0	OPEN	MAINT	MAINT	ON	1.58	20
00:07:38	2200	0.196	ROP	0	100	111	100	0	OPEN	MAINT	MAINT	ON	1.58	20
00:09:32	2200	0.196	ROP	0	100	111	100	0	OPEN	MAINT	MAINT	ON	1.6	20
00:09:34	2200	0.196	ROP	0	100	111	100	0	OPEN	MAINT	MAINT	ON	1.61	20
00:23:47	2200	0.196	ROP	0	100	111	87.73	0	OPEN	MAINT	MAINT	ON	1.61	20
00:23:48	2200	0.196	ROP	0	100	111	88.28	0	OPEN	MAINT	MAINT	ON	1.61	20
00:24:04	2200	0.196	ROP	0	100	111	54.6	0	OPEN	MAINT	MAINT	ON	1.61	20
00:24:05	2200	0.196	ROP	0	100	111	46.63	0	OPEN	MAINT	MAINT	ON	1.61	20
00:24:52	2200	0.196	ROP	0	100	111	42.95	0	OPEN	MAINT	MAINT	ON	1.61	20
00:24:53	2200	0.196	ROP	0	100	111	31.91	0	OPEN	MAINT	MAINT	ON	1.61	20
00:25:57	2200	0.196	ROP	0	100	111	31.91	0	OPEN	MAINT	MAINT	ON	1.55	20

(a) Setpoints for the first drilling duration

Time (hh:mm:ss)	Flow rate (l/min)	Velocity (m/s)	Auto driller	WOB (kN)	ROP (m/h)	RPM (rpm)	Choke open (%)	Choke flow rate (l/min)	BOP	Active pH	Return pH	Control active pH	Active pH density (g/cc)	Active pH temperature (°C)
01:09:24	2450	0.196	ROP	0	100	111	25.17	0	OPEN	MAINT	MAINT	ON	1.59	20
01:09:25	2450	0.196	ROP	0	100	111	37.64	0	OPEN	MAINT	MAINT	ON	1.59	20
01:09:26	2450	0.196	ROP	0	100	111	39.89	0	OPEN	MAINT	MAINT	ON	1.59	20
01:09:51	2400	0.196	ROP	0	100	111	29.60	0	OPEN	MAINT	MAINT	ON	1.59	20
01:09:52	2400	0.196	ROP	0	100	111	25.78	0	OPEN	MAINT	MAINT	ON	1.59	20
01:09:58	2400	0.196	ROP	0	100	111	23.33	0	OPEN	MAINT	MAINT	ON	1.59	20
01:10:03	2400	0.196	ROP	0	100	111	22.71	0	OPEN	MAINT	MAINT	ON	1.59	20
01:10:09	2400	0.196	ROP	0	100	111	21.49	0	OPEN	MAINT	MAINT	ON	1.59	20
01:10:34	2400	0.196	ROP	0	100	111	17.8	0	OPEN	MAINT	MAINT	ON	1.59	20
01:10:43	2400	0.196	ROP	0	100	111	17.19	0	OPEN	MAINT	MAINT	ON	1.59	20
01:11:13	2400	0.196	ROP	0	100	111	17.8	0	OPEN	MAINT	MAINT	ON	1.59	20
01:11:14	2400	0.196	ROP	0	100	111	18.82	0	OPEN	MAINT	MAINT	ON	1.59	20
01:11:37	2400	0.196	ROP	0	100	111	19.03	0	OPEN	MAINT	MAINT	ON	1.59	20
01:11:38	2400	0.196	ROP	0	100	111	19.65	0	OPEN	MAINT	MAINT	ON	1.59	20
01:11:41	2400	0.196	ROP	0	100	111	20.26	0	OPEN	MAINT	MAINT	ON	1.59	20

(b) Setpoints for the last drilling duration

Figure 7.8: Setpoints for drilling operation with no influx or loss

Figure [7.7] is an example for drilling operation with initial setpoints as follow

- Main pump flow rate = 2550 l/min
- Surface RPM = 111 rpm
- Drill string velocity = 0.196 m/s
- ROP = 100 m/h
- Mud pits for main fluid = 1.55 sg
- Choke Opening = 100%

, that shows that the graphs which are used to observe the bottomhole pressure value, density, choke opening, and pump pressure, aid in adjusting BHP and ECD while maintaining the well safe. Setpoints for whole drilling duration is exported as CSV file as can be used as standard setpoints by clicking sequence option, see [7.8]

2. Well operation with influx and loss:

After identifying the factors affecting bottomhole pressure and running simulations for drilling operations with no influx and loss incidents, the simulation has been rerun with regard to influx and loss and the factors affecting BHP,

demonstrating the MPD role in maintaining well integrity and optimal handling during kick occurrences.

OpenLab display shows total influx and loss mass through the reservoir flow, and gas volume can be a criterion of kick occurrence. Bottomhole pressure and ECD can also identify the incidents when the bottomhole pressure is lower than the pore pressure during the kick incident or when the BHP is higher than the fracturing pressure during lost circulation.

To avoid kick and loss occurrence, it has been a demand to control BHP by manipulating the parameters such as density, pump flow rate and using MPD method, which has an essential role, using the backpressure and choke flow rate where:

$$\text{BHP} = \text{Hydrostatic Pressure} + \text{Friction Gradient Pressure} + \text{Back Pressure}$$

To run the simulation with loss and influx incidents, the user chooses running simulation based on geopressure influx and loss from drilling incidents. Three examples are given below, show the incident occurrences and how to handle the incidents to obtain well integrity with optimal solutions:

(a) Influx example and manage the well integrity:

Based on the Reservoir flow graph, the occurrence of a kick in this example starts from time = 00.22.31 and begins to stabilize in time = 00.34.34, to start again increasing in Time = 00.42.25 to final stabilization at Time = 01.00.07, then circulating out of well by using optimization of MPD where the total influx mass has been calculated, and = 4717 kg, see figure [7.9].

Increasing the pit gain is definitely one of the kick detection criteria by displaying the amount of replaced fluid by gas. Based on Pit volumes graph, the volume of kick can be calculated depending on the determination of the occurrence of kick period. Two kicks have occurred in this example, where the kick volume = $(44.18-26.16)+(42.18-36.46) = 23.18 \text{ m}^3$ see figure[7.9].

Figure [7.10] illustrates the moment the kick emergence. The volume of gas in the well grows, which may be tracked using a gas volume graph, before it becomes too large and reaches the surface, resulting in a blowout. Figure [7.11] shows how to handle kick incident using MPD methodology (backpressure and choke opening) and circulating the kick out of the well, thus avoiding the blowout risk.

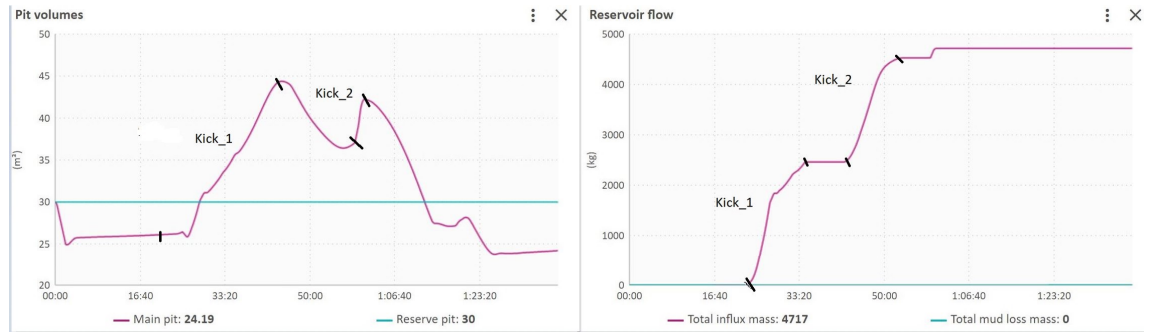


Figure 7.9: Influx mass and Pit volume

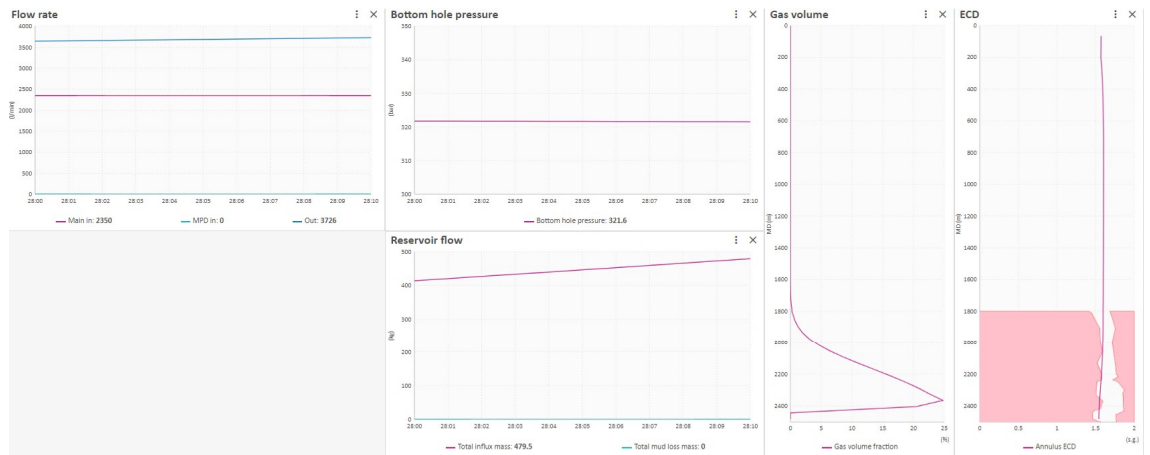


Figure 7.10: The moment the kick is occurred



Figure 7.11: Influx and circulating the kick out of the well

(b) loss example with no influx:

Mud loss can be shown in figure [7.12], where the setpoints are exported from CSV file. It has been tracked that the BHP is higher than fracture pressure based on reservoir flow and ECD graphs. This example demonstrates that the well is not in a safe state owing to the constant loss of drilling fluid, and that the right methods are needed to return the BHP and ECD to the safe limits.

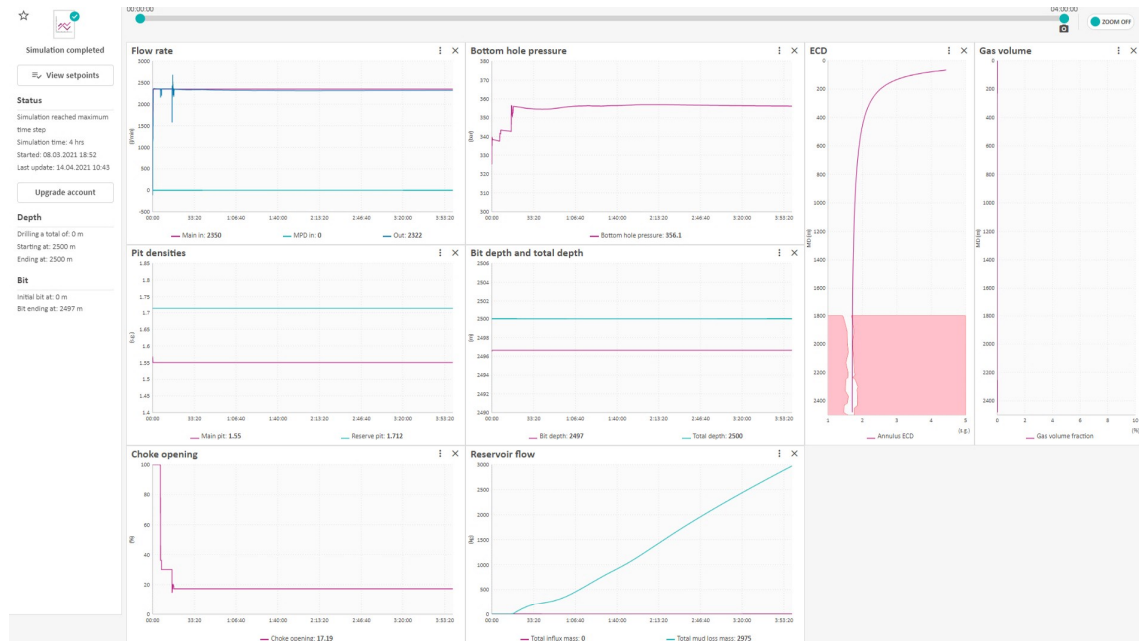


Figure 7.12: Monitored Mud loss example

(c) Influx and loss example, and manage the well integrity:

A flow sweep example which has been shown in figure [7.13] without drilling process are addressed with initial parameters:

- Main pump flow rate = 2450 l/min
- Choke Opening = 100 %
- Density = 1.55 sg

, testifies the influx and mud loss incident. Then it is a demand to manipulate the parameters to obtain ECD and BHP in a safe window avoiding influx and lost circulation incidents. The kick occurrence has been handled by using backpressure and closing the choke, adjusting the BHP to go back to the safe condition before the mass of influx increases and induces blowout. Lost circulation incident has been taken into account during increasing BHP. It was able to avoid an increase in BHP greater than fracture gradient pressure based on drilling by reducing the drilling fluid density and adjusting the choke opening using MPD technique features and drilling fluid characteristics.

In this scenario, a little kick with a total influx mass of 11.7 kg occurred, which was monitored and circulated out of the wellbore before it escalated and reached the surface, creating a blowout risk, while the total loss mass measured was 5174 kg.



Figure 7.13: Example with loss and influx

• Running Simulation from Matlab

Another option is to run simulations in Matlab or Python while monitoring from OpenLab. The connection between Matlab and OpenLab can be obtained using the Matlab login script With API Key, Username/E-mail and License ID, which is given in the OpenLab settings. Hence, Matlab is being used as a platform to run the simulation, and OpenLab is being used as a monitor to display processing graphs and observe the well condition.

Matlab client can be found and downloaded from OpenLab homepage [URL] as a zip file. The downloaded file contains a number of files that can be opened in Matlab, including GetLoginData, Drilling, FlowSweep_BHPCControl, InfluxBasedOnGeoPressure, ManualInflux, PIcontroller and OpenLabClient, which show the match setpoints and parameters coding in OpenLab and Matlab, that aids in the development of the simulation object. Unzipping the file and importing it in Matlab allows to run a simulation for the desired well operation and try to fix any problems.

What do we need to run simulation from Matlab?

In addition, to unzip the Matlab Client file from the OpenLab homepage and open the files in Matlab, we need to:

1. Open GetLoginData script to connect with OpenLab

2. Give the Configuration name which is created in OpenLab
3. Define the initial parameters
4. Give a simulation duration
5. Create a simulation object

Note: a Matlab R2016b version or later is required to run the OpenLab simulator, and setpoints are set in SI units.

The Implements are used in Matlab :

1. Using Matlab to run Flow Sweep and control BHP

After Opening the FlowSweep_BHPControl and given pre-made configuration name 'Case Study' which has already initial drilling fluid density 1.55 sg, it has been defined the desired initial setpoints as follows:

- Reference BHP Pressure = $340 * 1E5$ [pa]
- Initial Choke Opening = 0.25 where choke opening is between [0,1]
- Initial Bit Depth = 2500 [m]
- Initial Top Of String Position = 20

By manipulating the initial setpoints, it is possible to obtain the optimal process, which provides the safe operation and maintain BHP in safe window. See figure [7.14]

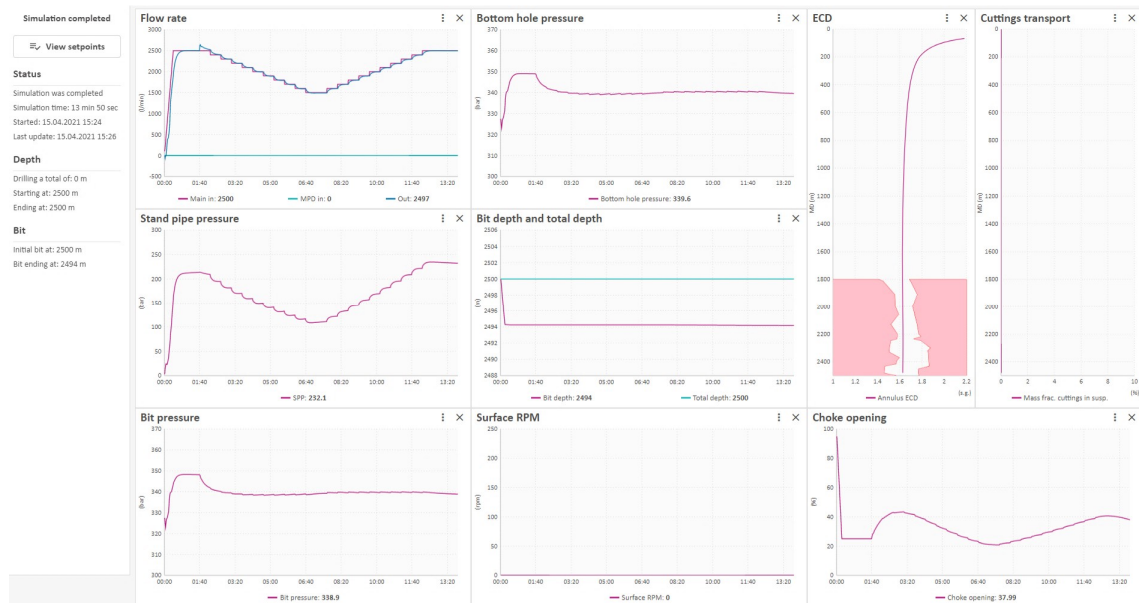


Figure 7.14: FlowSweep and BHP control from matlab

2. Using Matlab to run drilling

Initial setpoints:

- Flow Rate In = 0 [m3/sec]
- Top Of String Velocity = 0 [m/sec]
- ROP = 0 [m/sec]
- Surface RPM = 0[revolutions per sec.]
- Choke Opening = 1 where choke opening in range [0-1]
- Choke Pump Flow Rate In = 0 [m3/sec]
- Density In = 1.55 sg * 1E3 [kg/m3]
- BOP Choke Opening = 1 in range [0,1] where ROP = 1 is Open and ROP = 0 is closed

Auto-Connection process during the well drilling operations can cause the BHP reduction and induce a kick in the well. To reduce the risk of this function, it has been developed a simulation code that maintains ECD and BHP in a safe window and avoids kick occurrence during Auto-connection by taking advantage of OpenLabClient sheet, as follows:

```
if Sim.Connection == true ;  
display("Connection in progress") ;  
end
```

The code can be used, manipulating the choke opening and choke flow rate according to the required well condition, see figure [7.15].

The figures and setpoints review that the hook speed has a positive value, thus the depth of bit increases. A positive Top of string speed value indicates that the bit is at the bottom and that the ROP setpoint will be overridden, While negative velocity indicates that the drillstring will be pulled up and ROP will no longer be utilized. See figure [7.15]

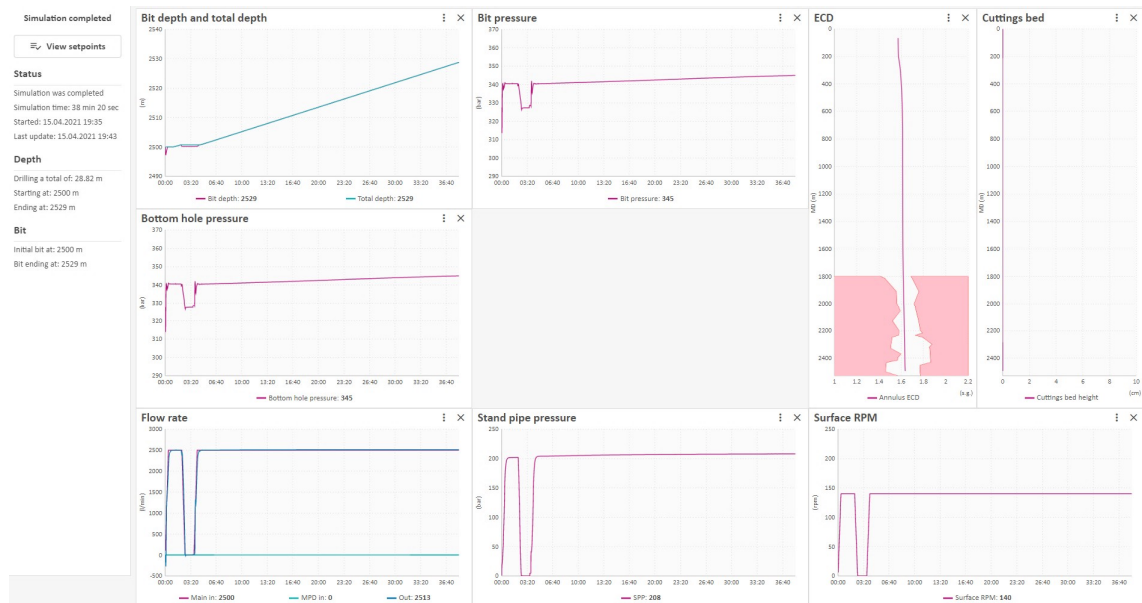


Figure 7.15: Drilling operation from Matlab

3. Using Matlab to run Influx/Loss based on geopressure

Using Influx/loss configurations as below:

- Use Reservoir Model = true where false means no influx and loss, and true means influx and loss.
- Manual Reservoir Mode = false, in which true refers to manual influx/loss and false refers to influx based on geothermal (only if Use Reservoir Model is true).
- Manual Influx Loss Mass Rate = 0 [kg/s] and here positive value for influx and negative value for loss.
- Manual Influx Loss Total Mass = 0 [kg]
- Manual Influx Loss MD = Initial Bit Depth = 2500 [m]
- Reservoir Kick Off Time = 15 [s]

and Setpoints to the simulator

- Top Of String Velocity = 0
- Surface RPM = 0
- Choke Pump Flow Rate In = 0
- Choke Opening = 1
- BOP Choke Opening = 1

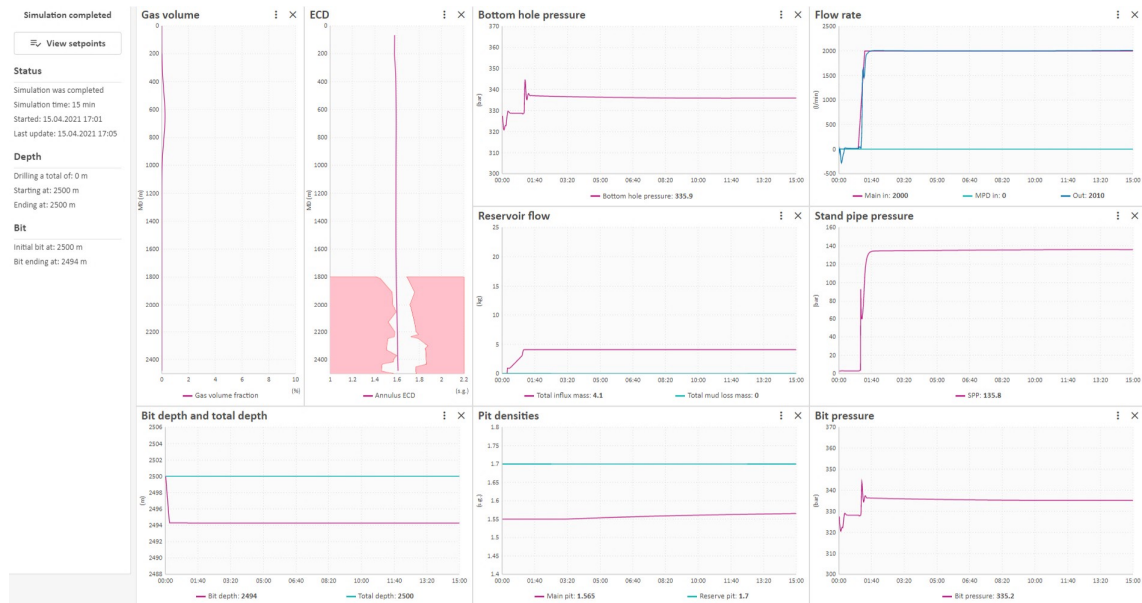


Figure 7.16: Influx/Loss Based on Geopressure from Matlab

The kick incident occurs when the BHP falls below the fluid formation pressure until it is controlled and circulated out of the well, which may be monitored using the Reservoir flow, Gas Volume, BHP, and ECD graphs. See figure [7.16]

4. Using Matlab to run manual Influx/Loss

Influx/Loss configurations with Initial Bit Depth = 2400 [m] and Initial Top Of String Position = 20

- Use Reservoir Model = true, false: no influx and loss, true: influx and loss.
- Manual Reservoir Mode = false, true: manual influx/loss, false: influx based on geo-thermal (only if UseReservoirModel is true)
- Manual Influx Loss Mass Rate = 0 [kg/s] (positive for influx, negative for loss)
- Manual Influx Loss Total Mass = 0 [kg]
- Manual Influx Loss MD = Initial Bit Depth = 2500 [m]
- Reservoir Kick Off Time = 15 [s]

Two examples have been shown in this case. Example [A], figure [7.17], indicates Loss event with no control during the time set in Matlab, in which the BHP is higher than the fracture pressure gradient whilst in example [B], figure [7.18], initial setpoints and definitely the choke opening has been manipulated

to reduce the BHP and keep it in the safe window between Pore pressure and fracture pressure.

Table [7.1] illustrates the difference of the setpoints, which are used in simulation between example [A] and example [B]

Setpoints	Example A	Example B
Top Of String Velocity	0	0
Surface RPM	0	0
Choke Pump Flow Rate In	0	0
Choke Opening	0,15	0,25
Bop Choke Opening	1	1
Flow Rate In	2000/60000	2000/60000

Table 7.1: Setpoints to simulate from Matlab (Manual Influx/Loss)

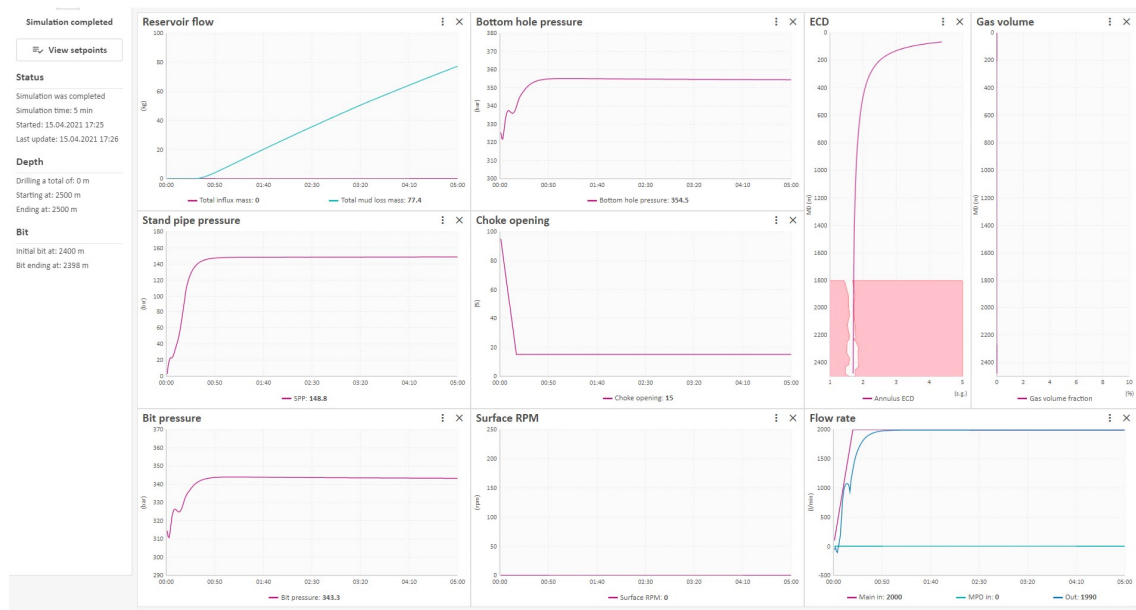


Figure 7.17: Manual Influx and Loss Example A

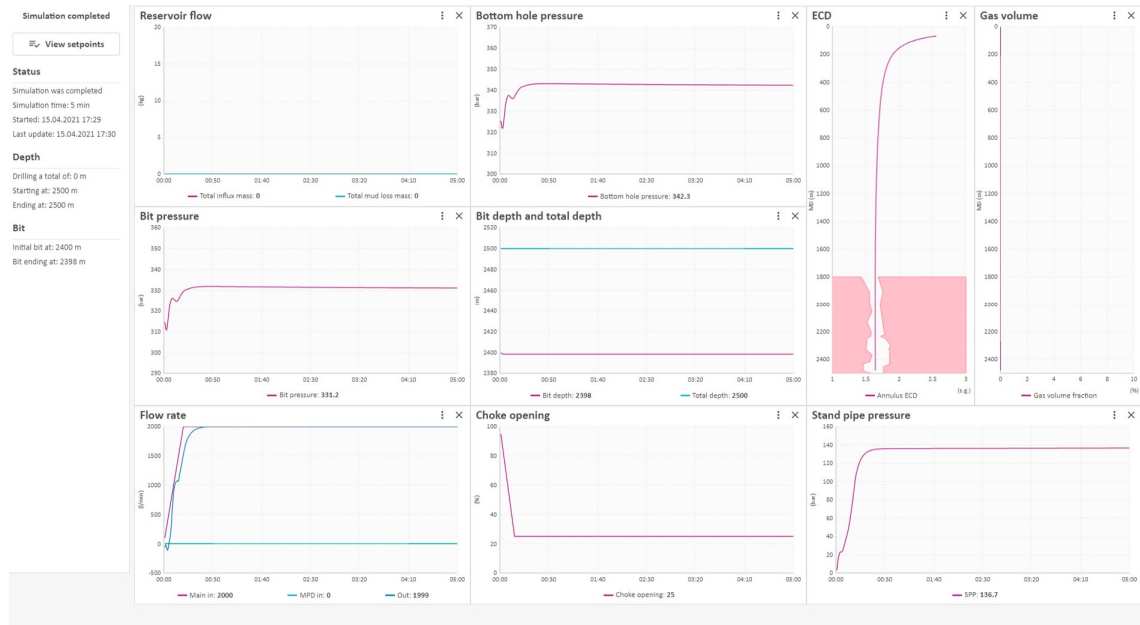


Figure 7.18: Manual Influx and Loss Example B

During simulation from Matlab, the feedback PI controller is used to control the system and K_p , and K_i gains values are given in Matlab coding.

The sequences of setpoints obtained during simulation in various scenarios, while optimizing the MPD and drilling fluid parameters, have been converted from CSV files to PDF and are presented in the Appendix.

Chapter 8

Results and Conclusion

8.1 Introduction

In this chapter, the forms and arguments that provides the framework for a simulation based drilling optimization approach will be presented. A work flow algorithm that optimizes the drilling process has been developed using the OpenLab simulator and Matlab.

8.2 Block Diagram of cases

8.2.1 Configuration of case study

When utilizing the OpenLab simulator, the following settings are required to configure the case study, see figure [8.1]:

- Geology
- Rig
- Drill String
- Hole section
- Fluid
- Well Path

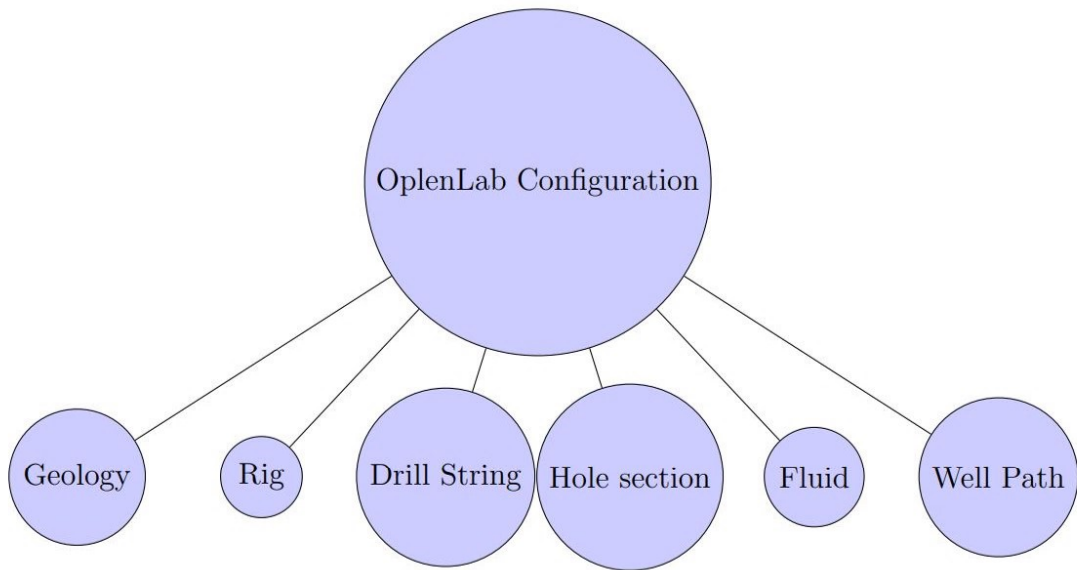


Figure 8.1: OpenLab configuration

8.2.2 Drilling process requirements

In order to run a drilling simulation, a set of important drilling parameters must be configured, as shown in figure [8.2]:

- Flow Rate
- Open ROP
- WOB
- Hook Speed
- RPM
- Bit on Bottom

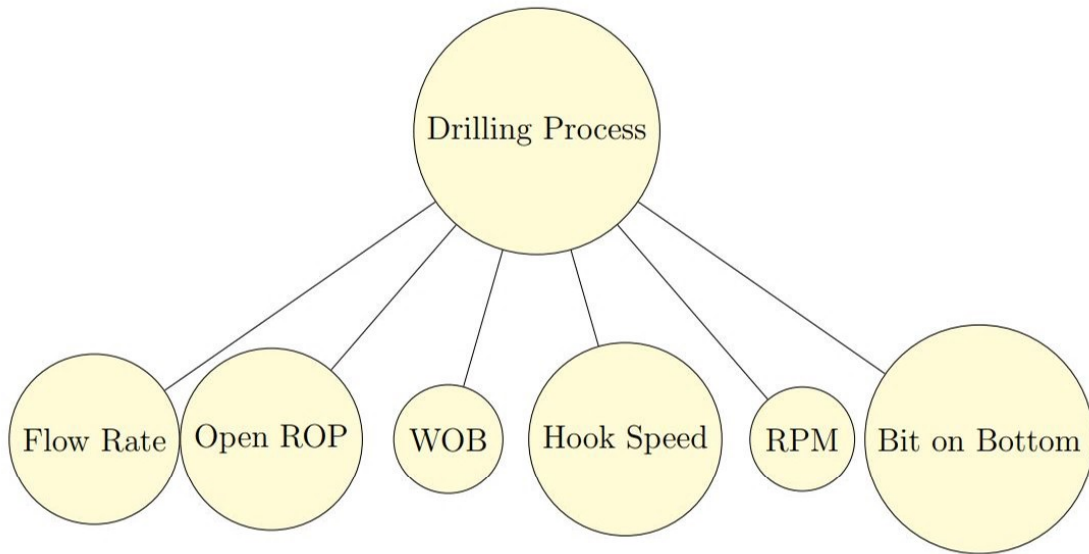


Figure 8.2: Drilling process requirements

8.2.3 Influx and lost circulation incidents

The following figures ([8.3],[8.4]) below show the most relevant OpenLab variables that must be monitored in order to detect the key concerns such as the influx incident [8.3] and lost circulation [8.4]:

Influx determination

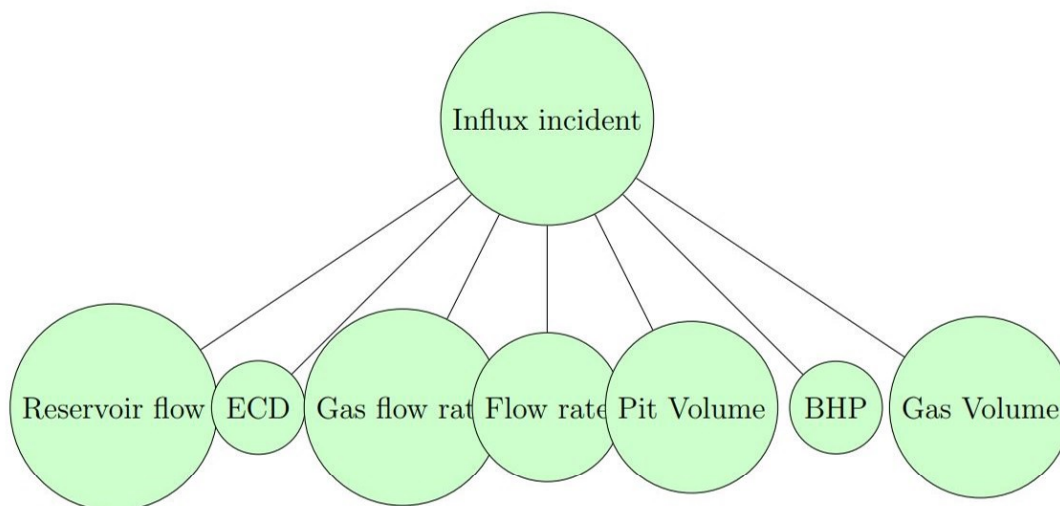


Figure 8.3: influx incident detection

Lost circulation

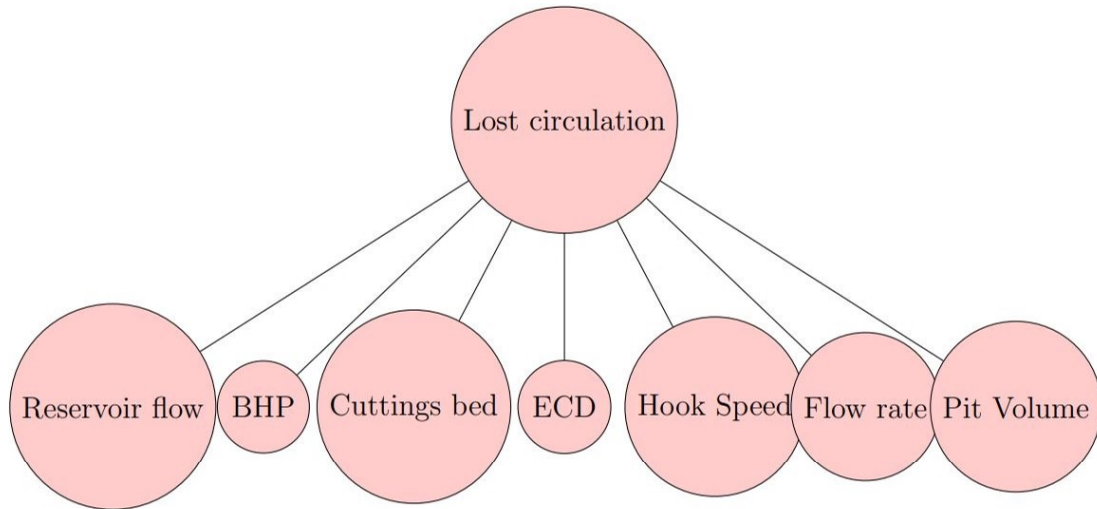


Figure 8.4: Lost circulation detection

8.2.4 Optimization MPD and Drilling fluid properties

Optimization of MPD and drilling fluid properties when drilling incidents such as kick or lost circulation occurs in narrow pressure margin wells can be obtained as follows:

Kick

During formation influx and kick occurrence, the ECD and BHP decrease to be lower than formation pore pressure.

By closing the choke and commencing to pump from the supplied backpressure pump in the MPD system, the ECD and BHP are increased and maintained between pore pressure and fracture pressure, keeping the well in safe mode.

A new heavier drilling fluid is used to replace the old drilling fluid in the wellbore to increase the ECD and BHP. This procedure takes some time to fill the annulus with the heavier drilling fluid, as seen by fluctuations in the ECD and BHP graphs, based on OpenLab simulator.

The MPD and drilling fluid characteristics are optimized by manipulating the parameters that regulate BHP and ECD as shown in figure [8.5] below:

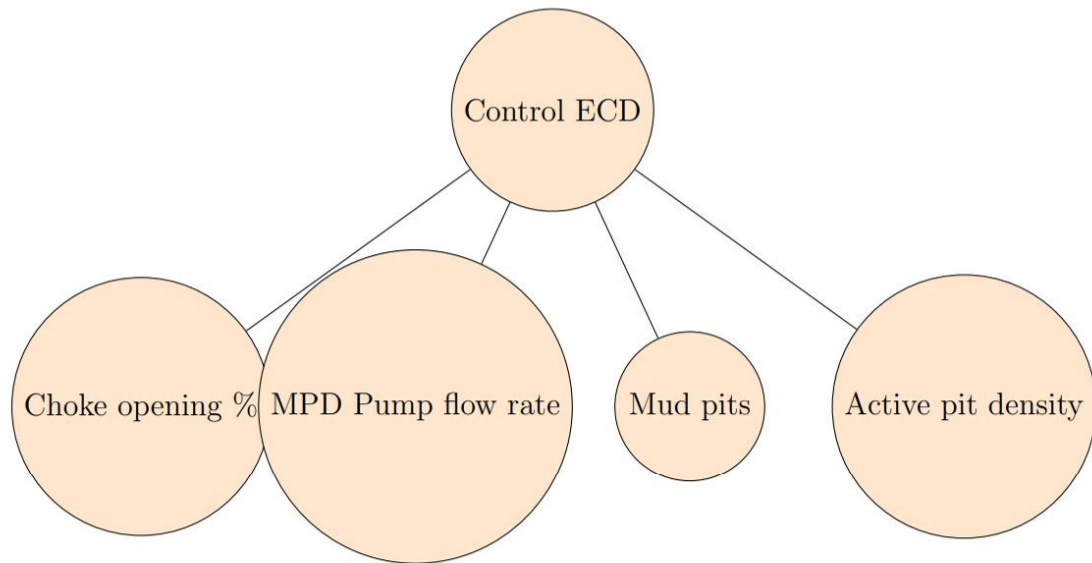


Figure 8.5: ECD control

Lost circulation

During lost circulation incidents, the ECD values rise above the fracture pressure gradient, causing drilling fluid to move into the formation.

The BHP and ECD are managed and maintained between pore pressure and fracture pressure by progressively opening the choke and lowering the pump pressure exerted by the provided pump in the MPD system, keeping the well in a safe mode. A new lighter drilling fluid is used to replace the old drilling fluid in the wellbore to reduce the ECD and BHP. This procedure takes some time to fill the annulus with the lighter drilling fluid, as seen by fluctuations in the ECD and BHP graphs, based on OpenLab simulator.

The MPD and drilling fluid characteristics are optimized by manipulating the parameters to control BHP and ECD as for the kick scenario, but with the purpose of reducing the well pressure.

Workflow algorithm

The workflow algorithm created using the Openlab simulator is shown in the flow diagram below. For narrow pressure margin wells, the work flow algorithm can be used to optimize the MPD and drilling fluid characteristics while taking into consideration drilling incidents that may occur in the wellbore.

Performing the simulation before and during drilling operation using OpenLab simulator can be illustrated as follows:

1- Configuration

1. Configure the geopressure profiles in the well model to replicate the expected geopressures in the field.
2. Configuring the riser, casing plan and open hole section by editing the hole section option (the length of openhole section = 700 m)
3. Select the properties for main drilling fluid, reserved fluid, and rheology.
4. Adding Alongstring measurements (ASM) to the Bottom hole assembly(BHA) if this is the case in the planned operation.

2- Simulation before drilling operation

1. Create a new simulation from the established configuration.
2. Setting up the simulation options using geopressure-based drilling incidents.
3. To start drilling, select starting values for flow Rate, hook speed (positive is downward), desired ROP, opening BOP, surface RPM are required.
4. Run simulation

3- Simulation during drilling operation

Running simulation considering the drilling incidents based on geobressure can be observed by time graphs and depth graphs with possibility of drilling incidents, such as kick and lost circulation.

1. During kick incident($ECD < P_{pore}$):
Two methods have been approached to handle kick occurrence and maintain ECD in a safe margin.
 - Based on drilling fluid density since the hydrostatic pressure is a function of density, the old drilling fluid has been replaced by a new heavier drilling fluid.
 - Based on MPD system, since the backpressure is inversely proportional to choke opening, choke valve has been gradually closed until send ECD profile bake to safe window.
2. During lost circulation incident($ECD > P_{fracture}$):
Losing drilling fluid into drilled formation can be handled as follows:
 - Based on drilling fluid density since the hydrostatic pressure is a function of density, the old drilling fluid has been replaced by a new lighter drilling fluid.
 - The flow rate (Q) has been deceased taking into account the holecleaning and Pack off incident.
 - By close the choke valve gradually when it is open during lost circulation incident.

3. During connection and drillstring tripping ($Q = 0$):
The pressure at downhole will decrease leading to encountering formation influx when ($ECD < P_{pore}$)
 - Running MPD system by decreasing choke opening, thus increasing backpressure to compensate the pressure reduction in the annular and avoid kick incident.

- Summary

The MPD method and selecting proper drilling fluid properties to maintain the BHP in a safe mode between pore pressure and fracture pressure and prevent drilling incidents have been employed as follows:

1. Opening the choke in MPD system, thus reducing the backpressure, leads to decrease the bottomhole pressure.
2. Closing the choke in MPD system, thus increasing the backpressure, leads to increase the bottomhole pressure.
3. Replacing the old drilling fluid by a new heavier one leads to increase the bottomhole pressure.
4. Replacing the old drilling fluid by a new lighter one leads to decrease the bottomhole pressure.
5. Decreasing flow rate leads to decrease bottomhole pressure.
6. MPD methodology and manipulating drilling fluid properties have been utilized in drilling system to optimize the drilling operation with respect to maintain the sufficient flow rate to achieve the efficiency hole-cleaning.

Figures ([8.6], [8.7]) illustrate the work-flow algorithm for a planned drilling operation [8.6] and of real drilling operation for narrow pressure margin wells [8.7], when using OpenLab simulator to assist in the choice of drilling parameters.

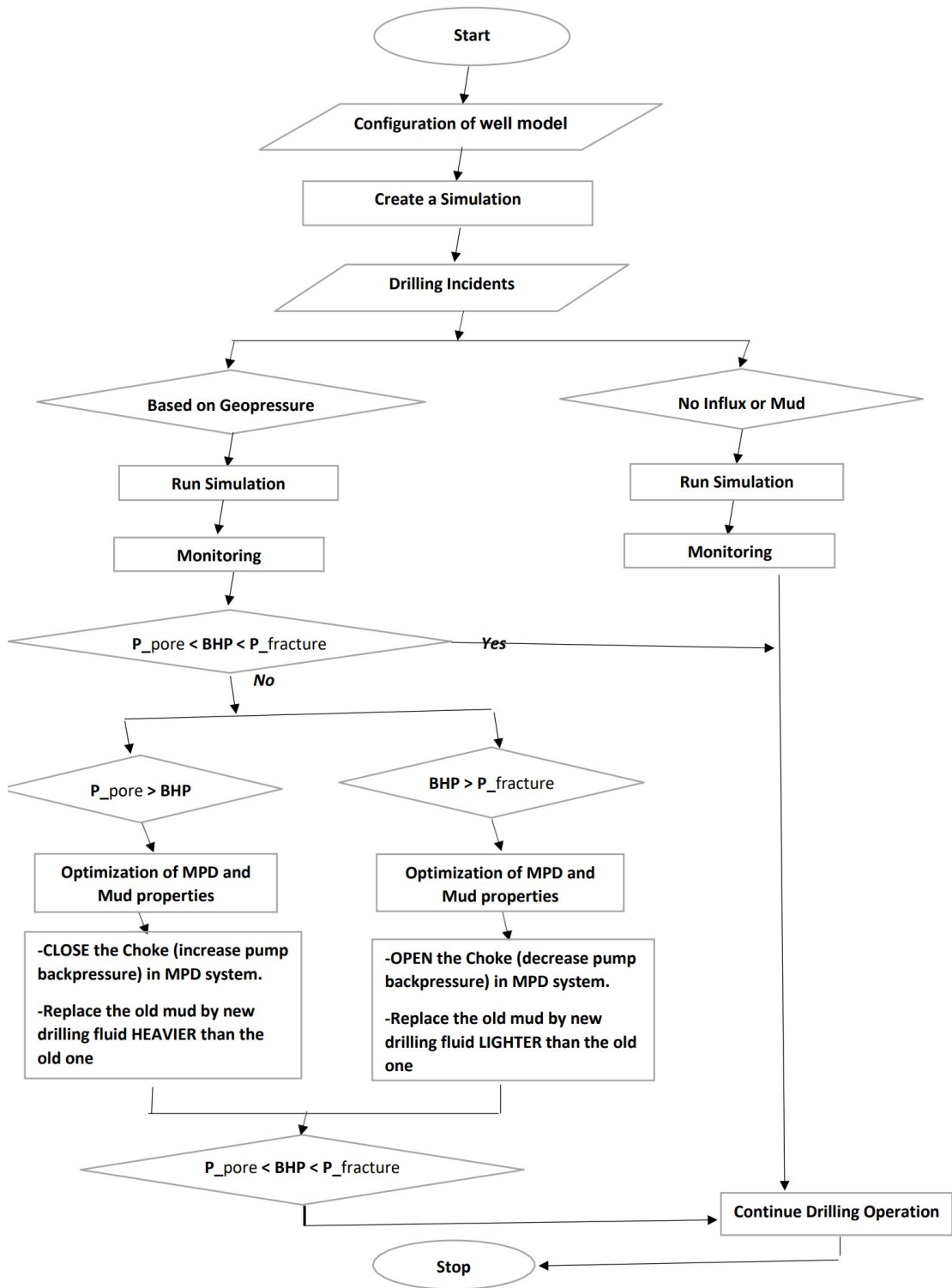


Figure 8.6: Work-flow algorithm when using the OpenLab simulator to find optimum MPD settings and mud properties for a planned drilling operation

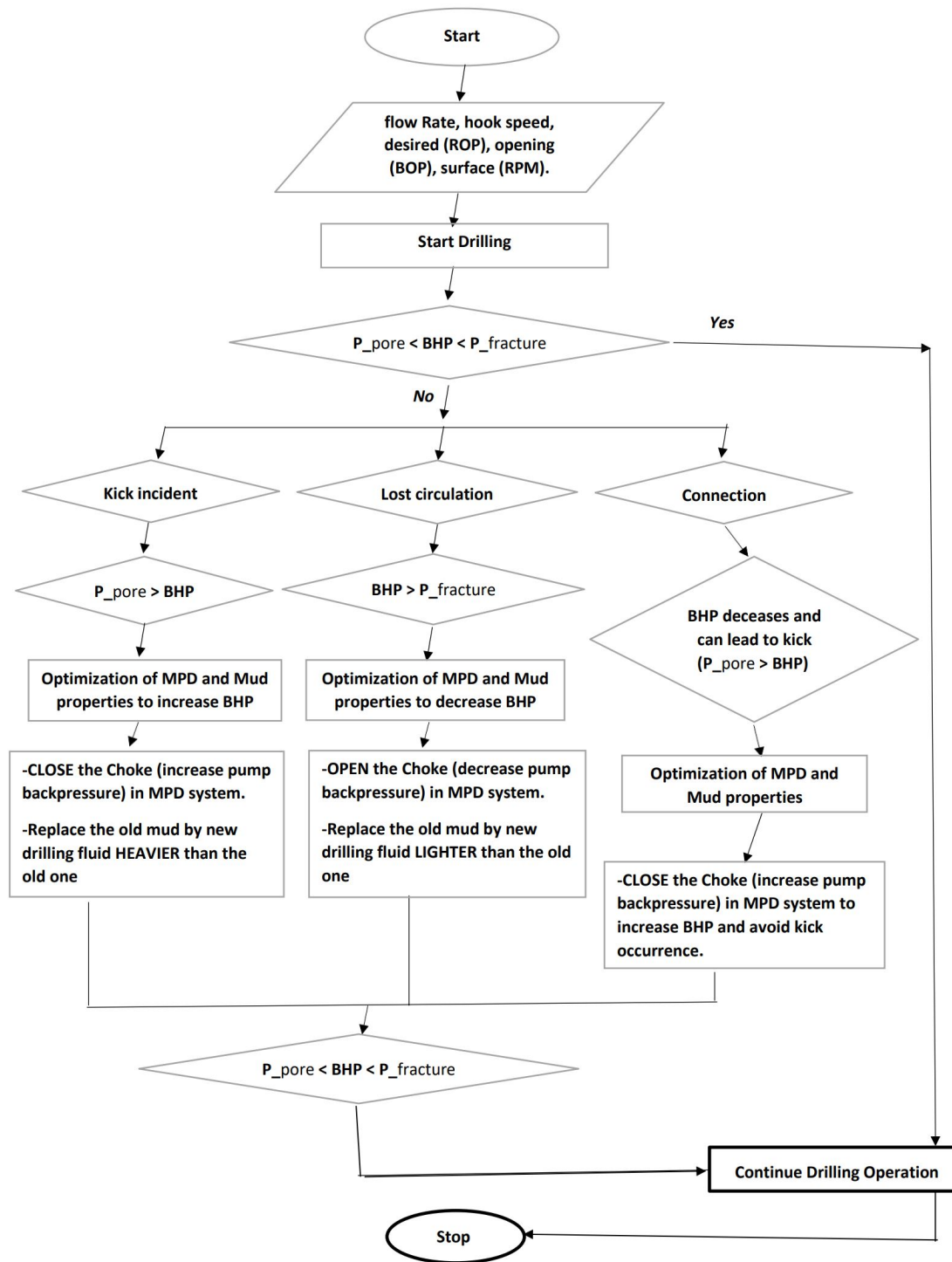


Figure 8.7: Work-flow algorithm of real drilling operation for narrow pressure margin wells, using the OpenLab simulator to assist in the choice of drilling parameters

8.3 Conclusion

During the last decade, the oil and gas sector has demonstrated significant improvements in autonomous system innovations and development, motivated by increased recovery and new fields in challenging formations with narrow pressure window.

According to oil and gas companies, the oil and gas sector tends to steadily expand drilling operations in narrow pressure margin wells, representing the future oil and gas energy source. Drilling operations in narrow pressure margin wells require more "accuracy and sensitivity" during drilling operations because the pore pressure is often close to the fracture pressure, resulting in a higher probability of well incidents compared to wells with a wider pressure window.

Bottomhole pressure may fall below pore pressure during connections or when tripping out, or it can exceed fracture pressure when high circulation rate is applied. This can cause well incidents such as formation influx, lost circulation, stuck pipe, and so on. The result is higher non-productive time (NPT), drilling expenses, and human hazards.

When the pore pressure exceeds the well pressure a kick may occur. Thus, using the MPD backpressure and progressively closing the choke valve assist in stabilizing the ECD in the annulus by maintaining the ECD greater than the pore pressure gradient. However, if the ECD becomes greater than the fracture pressure gradient, a lost circulation incident can occur. The choke valve in the MPD system can then be opened to reduce the BHP and maintain the ECD lower than the fracture pressure gradient.

The selection of drilling fluid with appropriate density and rheology is critical to optimize drilling operations and mitigate incidents. Replacing the initial drilling fluid with a heavier fluid is a way to mitigate further influx, and the new density and rheology must be chosen carefully. In the same way, a lighter fluid must be selected to mitigate lost circulation problems. However, the optimum combination of mud properties and MPD settings can be challenging to find.

The use of simulations to support the optimization of MPD and drilling fluid properties based on OpenLab simulator and Matlab have been expounded on in this thesis in chapters 7 and 8. Using the MPD methodology and selecting the appropriate drilling fluid characteristics and rheology are crucial in narrow pressure margin wells to keep the bottomhole pressure between pore pressure and fracture pressure, thereby maintaining the wellbore in stability mode. As a result, well integrity, which is achieved by using MPD backpressure, utilizing the provided choke line in the MPD system, and selecting the appropriate drilling fluid with proper density and rheology, is required to avoid well incidents, thereby reducing NPT, drilling costs, ensuring the safety environment, and reducing hazards that can threaten human safety.

Appendix A

Appendix

A.1 Case Description

A.1.1 Configuration of Study Case

Rig

Main pump	Max flow rate acceleration	100 l/min/sec
MPD pump	Max flow rate acceleration	100 l/min/sec
MPD choke	Max change rate	5 %/sec
MPD choke	Choke opening diameter	3 in
MPD choke	Choke constant	1.975
MPD choke	Choke characteristics	Choke opening (%) with Value [0-1]
BOP choke	Max change rate	5 %/sec
Travelling block	Travelling block weight	20 ton
Top drive	Max rotation acceleration	6 rpm/sec
Drawworks	Max top of string acceleration	0.3 m/s ²
Shaker	Mud loss proportion	0 %
Main tank	Tank volume	40 m ³
Reserve tank	Tank volume	40 m ³

Table A.1: Rig components

Geology

1- Formation

MD (m)	UCS (MPa)	Friction angle (°)
0	100	30
2502	100	30
2503	100	30
2506	100	30
2507	100	30

Table A.2: Formation strength

2-Geothermal

Air temperature (°C)	10
----------------------	----

Table A.3: Air

From TVD (m)	Temp. gradient (°C/100m)
40	-2

Table A.4: Water

From TVD (m)	Temp. gradient (°C/100m)
200	3
730	3
930	3
980	3
1150	3
1400	3
1632	4.5
1741	4.5
1872	4.5
193	4.5
2138	4.5
2800	3
3200	3
3300	3

Table A.5: Solid

3- Geopressure

#	TVD (m)	Pore pressure (s.g.)	Fracture pressure (s.g.)
1	400	0.8	1.179
2	500	0.85	1.271
3	600	0.88	1.329
4	700	0.91	1.379
5	800	0.93	1.418
6	900	0.945	1.448
7	1000	0.952	1.456
8	1100	0.96	1.464
9	1200	0.968	1.472
10	1300	0.975	1.483
11	1400	0.98	1.492
12	1430	0.982	1.494
13	1450	0.99	1.498
14	1470	1	1.505
15	1490	1.03	1.522
16	1500	1.04	1.528
17	1580	1.22	1.63
18	1635	1.45	1.7
19	1700	1.555	1.76
20	1760	1.56	1.718
21	1800	1.59	1.736
22	1850	1.52	1.758
23	1900	1.578	1.773
24	1915	1.578	1.794
25	1927	1.574	1.727
26	1937	1.518	1.793
27	1967	1.51	1.857
28	1977	1.507	1.878
29	1993	1.505	1.853
30	1999	1.503	1.858
31	2028	1.596	1.861
32	2046	1.568	1.863
33	2058	1.567	1.865
34	2070	1.465	1.866
35	2085	1.462	1.768
36	2106	1.459	1.77
37	2120	1.459	1.77
38	2153	1.566	1.775
39	2190	1.566	1.775
40	2300	1.566	1.775
41	2350	1.566	1.775
42	2400	1.566	1.775
43	2500	1.566	1.775
44	2600	1.566	1.775
45	2700	1.566	1.775
46	2800	1.566	1.775

Table A.6: Geopressures
Chapter A

Drillstring

Type	Length (m)	OD (in)	ID (in)	Lin.weight (kg/m)	Cum.length (m)
Drillpipe	3585	5	4.28	33	4251.3
Drillpipe	500	5	4 9/32	33	666.3

Table A.7: Drill Pipe

Type	Length (m)	OD (in)	ID (in)	Lin.weight (kg/m)	Cum.length (m)
HW drillpipe	54	5	3	76	166.3
ASM	2	7 1/5	5 1/5	98.6	112.3
Jar	9.4	6 1/2	2 1/2	139.7	110.3
HW drillpipe	44.9	5	3	76	100.9
Drill collar	28.8	6 1/2	2 13/16	145.7	56
MWD	7.9	6 7/8	3	139.6	27.2
ASM	2	7 1/5	5 1/5	98.6	19.3
LWD	6.4	6 7/8	3	134.6	17.3
Drill collar	2	5 1/2	3	84.5	10.9
Float sub	1	6 3/4	3	146.9	
Steerable rotary tool	7.7	6 3/4	3	148	8

Table A.8: Bottom hole assembly

Type	Length (m)	OD (in)	TFA (cm ²)	Mass (kg)	Cum.length (m)
Bit	0.3	8 1/2	6.3	50	0.3

Table A.9: Bit

Fluid

1- Main fluid

Fann shear stress measurements in lb/100ft² at 50 °C and 1 bar vs. shear rate

3 rpm	6 rpm	30 rpm	60 rpm	100 rpm	200 rpm	300 rpm	600 rpm
7.4	7.9	11.6	16	21.6	34.1	45.9	78.9

Table A.10: Rheology

	4°C	20°C	50°C	75°C	100°C	125°C	150°C	175°C	200°C
1 bar	0.819	0.809	0.79	0.775	0.758	0.744	0.727	0.712	0.696
200 bar	0.829	0.82	0.805	0.788	0.775	0.761	0.746	0.733	0.718
400 bar	0.838	0.83	0.815	0.803	0.789	0.776	0.765	0.751	0.738
600 bar	0.847	0.84	0.826	0.815	0.803	0.791	0.779	0.767	0.754
800 bar	0.856	0.848	0.836	0.825	0.815	0.803	0.793	0.782	0.77
1000 bar	0.864	0.856	0.845	0.835	0.824	0.814	0.803	0.793	0.782
1200 bar	0.87	0.864	0.852	0.842	0.832	0.822	0.812	0.802	0.791

Table A.11: Base-oil-pvt (s.g.)

2- Reserve Fluid

Fann shear stress measurements in lb/100ft² at 50 °C and 1 bar vs. shear rate

3 rpm	6 rpm	30 rpm	60 rpm	100 rpm	200 rpm	300 rpm	600 rpm
8.5	10.3	16.5	21.9	27.3	36.9	44.2	60.9

Table A.12: Caption

WellPath1

#	MD (m)	Inc. (°)	Azimuth (°)	TVD (m)	DLS (°/30m)
1	0	0	0	0	0
2	43.5	0	0	43.5	0
3	152	0	40.6	152	0
4	291	0	360	291	0
5	301	0.27	180.37	301	0.81
6	311	0.29	174.74	311	0.1
7	321	0.24	172.9	321	0.15
8	331	0.17	192.63	331	0.3
9	341	0.17	232.7	341	0.35
10	351	0.19	231.94	351	0.06
11	361	0.25	195.7	361	0.44
12	371	0.13	194.19	371	0.36
13	381	0.1	309.46	381	0.58
14	391	0.12	288.51	391	0.13
15	401	0.14	248.95	401	0.27
16	411	0.25	214.46	411	0.47
17	421	0.39	193.84	421	0.5
18	431	0.33	173.65	431	0.42
19	441	0.23	115.8	441	0.85
20	451	0.37	77.82	451	0.71
21	461	0.39	72.57	461	0.12
22	471	0.2	95.72	471	0.66
23	481	0.2	162.91	481	0.66
24	491	0.31	154.82	491	0.35
25	501	0.26	149.29	501	0.17
26	511	0.23	152.96	511	0.1
27	521	0.37	145.39	521	0.44
28	531	0.44	145.9	531	0.21
29	541	0.39	144.1	541	0.15
30	551	0.27	134.02	551	0.4
31	561	0.19	144.09	561	0.27
32	571	0.32	136.05	571	0.4
33	581	0.46	129.87	581	0.44
34	591	0.43	139.12	591	0.23
35	601	0.48	141.82	601	0.16
36	611	0.54	135.37	611	0.25
37	621	0.47	127.57	621	0.29
38	631	0.39	122.87	631	0.26
39	641	0.39	129.13	641	0.13
40	651	0.44	143.68	651	0.35

Table A.13: Survey stations-1

WellPath2

#	MD (m)	Inc. (°)	Azimuth (°)	TVD (m)	DLS (°/30m)
41	661	0.55	152.3	661	0.4
42	671	0.71	161.7	671	0.57
43	681	0.86	179.94	681	0.87
44	691	1.18	203.66	691	1.57
45	701	1.86	218	701	2.32
46	711	2.6	222.5	711	2.28
47	721	3.32	223.45	721	2.16
48	731.1	4.04	223.02	731	2.16
49	741.1	4.75	222.88	741	2.12
50	751.1	5.48	224.41	751	2.22
51	761.2	6.27	225.84	761	2.4
52	771.3	7.1	226.82	771	2.5
53	781.3	7.91	227.48	781	2.42
54	791.4	8.63	228.12	791	2.15
55	801.6	9.36	229	801	2.2
56	811.7	10.12	229.57	811	2.26
57	821.9	10.73	229.78	821	1.8
58	832.1	11.31	229.91	831	1.71
59	842.3	11.95	230.17	841	1.89
60	852.5	12.72	230.49	851	2.26
61	862.8	13.54	230.9	861	2.41
62	873.1	14.36	231.27	871	2.4
63	883.4	15.23	231.5	881	2.53
64	893.8	15.89	231.58	891	1.91
65	904.2	16.33	231.69	901	1.27
66	914.7	16.71	231.86	911	1.1
67	925.1	17.13	231.83	921	1.21
68	935.6	17.57	231.75	931	1.26
69	946.1	17.93	231.9	941	1.04
70	956.6	18.29	232.03	951	1.03
71	967.1	18.71	232.05	961	1.2
72	977.7	19.17	232.06	971	1.31
73	988.3	19.69	232.2	981	1.48
74	999	20.28	232.28	991	1.67
75	1009.6	20.97	232.19	1001	1.94
76	1020.4	21.85	232.37	1011	2.46
77	1031.2	22.78	232.83	1021	2.63
78	1042.1	23.54	233.08	1031	2.11
79	1053	24.17	233.17	1041	1.73
80	1064	24.61	233.29	1051	1.21

Table A.14: Survey stations-2

WellPath3

#	MD (m)	Inc. (°)	Azimuth (°)	TVD (m)	DLS (°/30m)
81	1075	24.7	233.49	1061	0.49
82	1086	24.72	233.78	1071	0.36
83	1097	24.66	233.83	1081	0.17
84	1108	24.64	233.64	1091	0.22
85	1119	24.59	233.55	1101	0.17
86	1130	24.52	233.57	1111	0.19
87	1141	24.48	233.7	1121	0.18
88	1152	24.38	233.73	1131	0.28
89	1163	24.23	233.59	1141	0.44
90	1173.9	24.17	233.51	1151	0.19
91	1184.9	24.21	233.46	1161	0.12
92	1195.8	24.21	233.53	1171	0.08
93	1206.8	24.07	233.82	1181	0.5
94	1217.7	23.93	234.01	1191	0.44
95	1228.7	23.91	234.03	1201	0.06
96	1239.6	23.86	234.03	1211	0.14
97	1250.6	23.77	234.05	1221	0.25
98	1260	24.71	237.71	1229.6	5.63
99	1270	25.51	239.38	1238.7	3.21
100	1280	26.06	239.75	1247.7	1.72
101	1290	26.62	239.95	1256.6	1.7
102	1300	27.18	239.76	1265.6	1.7
103	1310	27.8	239.56	1274.4	1.88
104	1320	28.76	238.99	1283.2	2.99
105	1330	29.65	238.92	1292	2.67
106	1340	30.47	238.52	1300.6	2.53
107	1350	31.46	238.02	1309.2	3.07
108	1360	32.29	237.78	1317.7	2.52
109	1370	33.23	237.54	1326.1	2.85
110	1380	34.15	237.35	1334.4	2.78
111	1390	35.25	236.89	1342.6	3.39
112	1400	36.28	236.86	1350.7	3.09
113	1410	37.35	236.78	1358.8	3.21
114	1420	38.44	236.59	1366.6	3.29
115	1430	39.45	236.72	1374.4	3.04
116	1440	40.31	236.61	1382.1	2.59
117	1450	41.16	236.82	1389.7	2.58
118	1460	41.99	237.02	1397.2	2.52
119	1470	42.8	236.98	1404.5	2.43
120	1480	43.59	236.76	1411.8	2.41

Table A.15: Survey stations-3

WellPath4

#	MD (m)	Inc. (°)	Azimuth (°)	TVD (m)	DLS (°/30m)
121	1490	44.51	236.76	1419	2.76
122	1500	45.37	236.82	1426.1	2.58
123	1510	46.35	236.87	1433.1	2.94
124	1520	47.14	237.31	1439.9	2.56
125	1530	47.62	237.94	1446.7	2
126	1540	47.96	238.17	1453.4	1.14
127	1550	48.12	238.24	1460.1	0.5
128	1560	48.25	237.82	1466.8	1.02
129	1570	48.24	238.01	1473.4	0.43
130	1580	48.3	237.99	1480.1	0.19
131	1590	48.32	237.79	1486.7	0.45
132	1600	48.3	237.58	1493.4	0.47
133	1610	48.48	237.3	1500	0.83
134	1620	48.37	237.29	1506.6	0.33
135	1630	48.41	237.35	1513.3	0.18
136	1640	48.37	237.41	1519.9	0.18
137	1650	48.18	237.05	1526.6	0.99
138	1660	48.12	237.05	1533.3	0.18
139	1670	48.27	237.18	1539.9	0.54
140	1680	48.37	237.37	1546.6	0.52
141	1690	48.59	237.29	1553.2	0.68
142	1700	48.62	237.32	1559.8	0.11
143	1710	48.28	237.86	1566.4	1.58
144	1720	48.07	237.84	1573.1	0.63
145	1730	47.82	238.16	1579.8	1.03
146	1740	47.82	238.15	1586.5	0.02
147	1750	47.82	238.08	1593.2	0.16
148	1760	47.91	238.28	1600	0.52
149	1770	47.92	238.4	1606.7	0.34
150	1780	48.02	238.31	1613.3	0.4
151	1790	47.72	238.39	1620.1	0.92
152	1800	47.7	238.3	1626.8	0.21
153	1810	47.82	238.08	1633.5	0.61
154	1820	47.91	238	1640.2	0.32
155	1830	47.97	237.82	1646.9	0.44
156	1840	47.84	237.8	1653.6	0.39
157	1850	47.86	237.76	1660.3	0.11
158	1860	47.88	237.79	1667	0.09
159	1870	47.82	237.75	1673.8	0.2
160	1880	47.64	237.98	1680.5	0.74

Table A.16: Survey stations-4

WellPath5

#	MD (m)	Inc. (°)	Azimuth (°)	TVD (m)	DLS (°/30m)
161	1890	47.38	238.39	1687.2	1.2
162	1896	47.52	238.48	1691.3	0.78
163	1917.1	47.34	240.3	1705.6	1.92
164	1951.2	47.66	239.64	1728.6	0.51
165	1978.3	47.53	240.38	1746.9	0.62
166	2005.6	47.54	242.56	1765.3	1.77
167	2032.8	47.52	246.01	1783.7	2.8
168	2060.1	47.66	250.16	1802.1	3.37
169	2087.4	47.03	253.25	1820.6	2.59
170	2124.3	45.44	256.97	1846.1	2.54
171	2151.7	44.66	259.17	1865.5	1.91
172	2179.2	42.66	259.12	1885.4	2.18
173	2206.7	41.12	259	1905.8	1.68
174	2233.6	39.96	260.78	1926.3	1.83
175	2260.4	39.88	269.65	1946.8	6.37
176	2287.4	40.44	276.64	1967.5	5.05
177	2314.4	40.5	281.68	1988	3.63
178	2341.6	43.81	283.21	2008.2	3.82
179	2368.9	47.93	283.45	2027.2	4.54
180	2396.3	47.88	284.7	2045.6	1.02

Table A.17: Survey stations-5

WellPath6

#	MD (m)	Inc. (°)	Azimuth (°)	TVD (m)	DLS (°/30m)
181	2423.2	46.12	285.1	2063.9	1.99
182	2450.7	44.27	285.61	2083.3	2.05
183	2477.7	42.4	285.99	2102.9	2.1
184	2504.9	41.2	286.03	2123.2	1.32
185	2532.1	41.35	285.46	2143.7	0.45
186	2559.6	41.39	285.13	2164.3	0.24
187	2573.7	41.35	285.4	2174.9	0.39
188	2595	41.35	285.4	2190.9	0
189	2695	41.35	285.4	2265.9	0
190	2795	41.35	285.4	2341	0

Table A.18: Survey stations-6

HoleSection

Type	From depth (m)	To depth (m)	OD (in)	ID (in)
Riser	0	200	21	19

Table A.19: Riser

#	Type	Hanger depth (m)	Shoe depth (m)	OD (in)	ID (in)
1	Casing	200	422	32	30 3/4
2	Casing	200	465	26	25
3	Casing	200	950	20	18 23/32
4	Casing	200	1415	13 3/8	12 13/32
5	Casing	200	1600	10 3/4	9 15/16
6	Casing (liner)	1600	1800	9 7/8	9

Table A.20: Casings

Type	From length (m)	To length (m)	Length (m)	Open hole diameter (in)
Open hole	1800	2500	700	8 1/2

Table A.21: Open hole

A.2 Matlab Coding

A.2.1 FlowSweep_BHPControl_Coding

```
clear variables;
clc;
close all;
```

```
% subfolders
addpath(genpath(pwd));
```

```
IdentityServerURL = 'https://live.openlab.app/';
```

```
[username, api_key, license_guid] = GetLoginData();
```

```
ConfigurationName = 'Study Case';
SimulationName = 'Flow sweep with 1.55 sg (Matlab)';
InitialBitDepth = 2500; % [m]
InitialTopOfStringPosition = 20;
```

```
% Create simulation object
Sim = OpenLabClient(IdentityServerURL, username,api_key,license_guid,ConfigurationName,SimulationName,InitialTopOfStringPosition);
```

```

    % Ramp settings
    RampIndex = 1;
    RampValuesDown = (2500:-100:1500)/60000; % [m3/sec]
    RampValuesUp = (1500:100:2500)/60000; % [m3/sec]
    RampValues = [RampValuesDown RampValuesUp]; % [m3/sec]
    RampStepDuration = 30; % [sec]
    RampStartTime = 100; % [sec]
    RampTimeSteps = RampStartTime:RampStepDuration:length(RampValues)*RampStepDuration-
    1+RampStartTime;

    % Time steps to simulate
    MaxTimeSteps = (RampTimeSteps(end)+100);

    % Controller settings
    Kp = -0.015; Ki = Kp/10; Ts = 1;
    ReferenceBHPPressure = 340 * 1E5; % [Pa]
    InitialChokeOpening = 0.25; % [closed: 0, open: 1]
    PI = PIcontroller(Kp, Ki, Ts, ReferenceBHPPressure,InitialChokeOpening); % Cre-
    ate PI controller object, pressure in [Pa]

    if Sim.IsOK
    try
    for timeStep = 1 : MaxTimeSteps
    tStartStep = tic;

        if timeStep >= RampStartTime % Flow sweep and PI control of the choke
    if (RampIndex < length(RampTimeSteps) RampIndex < length(RampValues))
    if (timeStep >= RampTimeSteps(RampIndex) timeStep < RampTimeSteps(RampIndex
    + 1))
    FlowRateIn = RampValues(RampIndex);
    if (timeStep == RampTimeSteps(RampIndex + 1) - 1)
    RampIndex = RampIndex + 1;
    end
    end
    elseif (RampIndex == length(RampTimeSteps) RampIndex == length(RampValues))
    FlowRateIn = RampValues(RampIndex);
    end

        if timeStep == RampStartTime
    % Reset PI controller before usage, set reference value and initial output (= initial
    % choke opening)
    PI.Reset(ReferenceBHPPressure,Sim.ChokeOpeningStatus);
    end

        ChokeOpening = PI.GetOutput(Sim.BottomHolePressure); % Get choke open-
    ing from PI controller

        else % Constant flow rate and choke opening

```

```
FlowRateIn = RampValues(1);
ChokeOpening = InitialChokeOpening;
end

    % Set setpoints to the simulator
    Sim.FlowRateIn = FlowRateIn; % [m3/sec]
    Sim.ChokeOpening = ChokeOpening; % [0-1]
    Sim.ChokePumpFlowRateIn = 0/60000; % [m3/sec]
    Sim.TopOfStringVelocity = 0; % [m/sec]
    Sim.SurfaceRPM = 0/60; % [revolutions per sec.]
    Sim.ROP = 0/3600; % [m/sec]
    Sim.DensityIn= 1300; % mud density kg/m3
    Sim.MainPitReturn= true;
    Sim.ControlActivePitDensity= 1300;
    Sim.ControlActivePit =true;
    % Step simulator
    Sim.Step();

    if Sim.IsOK % Simulator fails
break;
end

    end

    % Stop simulation process
    Sim.Stop;

    catch exception
    % Stop simulation
    Sim.Stop;
    rethrow(exception);
end

    end
```

A.2.2 Drilling

```
clear variables;
clc;
close all;

    % subfolders
    addpath(genpath(pwd));

    IdentityServerURL = 'https://live.openlab.app/';
```

```

[username, api_key, license_guid] = GetLoginData();

ConfigurationName = 'Study Case';
SimulationName = 'Drilling sample (Matlab)';
InitialBitDepth = 2500; % [m]
InitialTopOfStringPosition = 5;

UseTransientMechanicalModel = false;
StepDuration = 1.0;

% Create simulation object
Sim = OpenLabClient(IdentityServerURL, username,api_key,license_guid,ConfigurationName,SimulationName,InitialTopOfStringPosition);

% Time steps to simulate
MaxTimeSteps = 2300;

% Initial setpoints
FlowRateIn = 0; % [m3/sec]
TopOfStringVelocity = 0; % [m/sec]
ROP = 0; % [m/sec]
SurfaceRPM = 0; % [revolutions per sec.]
ChokeOpening = 1; % [0-1]
ChokePumpFlowRateIn = 0; % [m3/sec]
DensityIn = nan; % [kg/m3]
BopChokeOpening = 1; % [0,1]

if Sim.IsOK
try
for timeStep = 1 : MaxTimeSteps
tStartStep = tic;

% Set setpoints to the simulator
if timeStep < 60
FlowRateIn = 2500/60000;
TopOfStringVelocity = 0.2; % [m/sec]
SurfaceRPM = 140/60; % [revolutions per sec.]

elseif timeStep > 250
ROP = 50/3600; % [m/sec]
TopOfStringVelocity = 0.2; % [m/sec]

else
FlowRateIn = 2500/60000; % [m3/sec]
TopOfStringVelocity = 0.2; % [m/sec]
ROP = 50/3600; % [m/sec]
end

```

```
    Sim.FlowRateIn = FlowRateIn;
    Sim.TopOfStringVelocity = TopOfStringVelocity;
    Sim.ROP = ROP;
    Sim.SurfaceRPM = SurfaceRPM;
    Sim.ChokeOpening = ChokeOpening;
    Sim.ChokePumpFlowRateIn = ChokePumpFlowRateIn;
    Sim.DensityIn = DensityIn;
    Sim.BopChokeOpening = BopChokeOpening;

    % Step simulator
    Sim.Step();

    if Sim.Connection== true
    disp('Connection in progress');
    end

    if Sim.IsOK % Simulator fails
    break;
    end

    display(['Total step duration: ' num2str(toc(tStartStep))]);
    end

    % Stop simulation process
    Sim.Stop;

    catch exception
    % Stop simulation
    Sim.Stop;
    rethrow(exception);
    end

    end
```

A.2.3 Influx/ Loss based on Geopressure

```
clear variables;
clc;
close all;

% subfolders
addpath(genpath(pwd));

IdentityServerURL = 'https://live.openlab.app/';

[username, api_key, license_guid] = GetLoginData();
```



```

    ConfigurationName = 'Study Case';
    SimulationName = 'Influx Based on Geopressure (Matlab)';
    InitialBitDepth = 2500; % [m]
    InitialTopOfStringPosition = 20;

    % Influx/loss configuration
    UseReservoirModel = true; % false: no influx and loss, true: influx and loss
    ManualReservoirMode = false; % true: manual influx/loss, false: influx based on
    geo-thermal (only if UseReservoirModel is
    true)
    ManualInfluxLossMassRate = 0; % [kg/s] (positive for influx, negative for loss)
    ManualInfluxLossTotalMass = 0; % [kg]
    ManualInfluxLossMD = InitialBitDepth; %2500; % [m]
    ReservoirKickOffTime = 15; % [s]

    % Create simulation object
    Sim = OpenLabClient(IdentityServerURL,username,api_key,license_guid,ConfigurationName,Simul
    tialTopOfStringPosition,...
    UseReservoirModel,ManualReservoirMode,ManualInfluxLossMassRate,ManualInfluxLossTotalMas

    if Sim.IsOK
    try
    for timeStep = 1 : 900
    tStartStep = tic;

        % Set setpoints to the simulator
        Sim.TopOfStringVelocity = 0;
        Sim.SurfaceRPM = 0;
        Sim.ChokePumpFlowRateIn = 0;
        Sim.ChokeOpening = 1;
        Sim.BopChokeOpening = 1;

        if timeStep < 60
        Sim.FlowRateIn = 0/60000;
        else
        Sim.FlowRateIn = 2000/60000;
        end

        Sim.Step();

        if Sim.IsOK
        break;
        end

    end

    % Stop simulation
    Sim.Stop;

```

```

        catch exception
    % Stop simulation
    Sim.Stop;

        rethrow(exception);
    end

    end

```

A.2.4 Manual Influx

```

clear variables;
clc;
close all;

% subfolders
addpath(genpath(pwd));

IdentityServerURL = 'https://live.openlab.app/';

[username, api_key, license_guid] = GetLoginData();

ConfigurationName = 'Study Case';
SimulationName = 'Manual influx (Matlab)';
InitialBitDepth = 2400; % [m]
InitialTopOfStringPosition = 20;

% Influx/loss configuration
UseReservoirModel = true; % false: no influx and loss, true: influx and los
ManualReservoirMode = false; % true: manual influx/loss, false: influx based on
geo-thermal (only if UseReservoirModel is
true)
ManualInfluxLossMassRate = 0; % [kg/s] (positive for influx, negative for loss)
ManualInfluxLossTotalMass = 0; % [kg]
ManualInfluxLossMD = InitialBitDepth; %2500; % [m]
ReservoirKickOffTime = 15; % [s]

% Create simulation object
Sim = OpenLabClient(IdentityServerURL,username,api_key,license_guid,ConfigurationName,SimulationName,
UseReservoirModel,ManualReservoirMode,ManualInfluxLossMassRate,ManualInfluxLossTotalMass,ReservoirKickOffTime);

if Sim.IsOK
try
for timeStep = 1 : 300
tStartStep = tic;

```

```

    % Set setpoints to the simulator
    Sim.TopOfStringVelocity = 0;
    Sim.SurfaceRPM = 0;
    Sim.ChokePumpFlowRateIn = 0;
    Sim.ChokeOpening = 0.25;
    Sim.BopChokeOpening = 1;
    Sim.FlowRateIn = 2000/60000;

    Sim.Step();

    if Sim.IsOK
    break;
end

    % GasVolumeFractionLog(timeStep,:) = [Sim.GasVolumeFraction(0) Sim.GasVolumeFraction(1000)
    Sim.GasVolumeFraction(2000) Sim.GasVolumeFraction(2200) ...
    % Sim.GasVolumeFraction(2300) Sim.GasVolumeFraction(2350) Sim.GasVolumeFraction(2400)
    Sim.GasVolumeFraction(2450) Sim.GasVolumeFraction(2500)];

    end

    % Stop Simulation process
    Sim.Stop;
    % figure; plot(GasVolumeFractionLog*100); title('GasVolumeFraction [%]'); grid;
    % legend('0m' '1000m' '1500m' '2200m' '2300m' '2350m' '2400m' '2450m' '2500m' );

    catch exception
    % Stop simulation
    Sim.Stop;

    rethrow(exception);
end

end

```

A.3 SI Metric Conversion Factors

- $\text{ft} \times 3.048 \times 10^1 = \text{m}$
- $\text{gal} \times 3.785412 \times 10^3 = \text{m}^3$
- $\text{in.} \times 2.54 \times 10^0 = \text{cm}$
- $\text{lbf} \times 4.535924 \times 10^1 = \text{kg}$
- $\text{psi} \times 6.894757 \times 10^0 = \text{kPa}$

A.4 Sequences of setpoints in different cases

Flow sweep with 1.55 sg (using Matlab)-simulation-sequence

Time (s);Main pump flow rate (l/min);Top of string speed (m/s);WOB auto driller
();WOB setpoint (ton);ROP setpoint (m/h);Surface RPM (rpm);Choke opening
(%);Pump flow rate (l/min);BOP (%);Active pit ();Return pit ();Control active pit
();Active pit density (s.g.);Active pit temperature (°C)

1;2500;0;;0;0;25;0;100;;true;true;1.3;-273.15
100;2500;0;;0;0;0;26.340427131835053;0;100;;true;true;1.3;-273.15
101;2500;0;;0;0;0;27.42808117983946;0;100;;true;true;1.3;-273.15
102;2500;0;;0;0;0;28.082122455948245;0;100;;true;true;1.3;-273.15
103;2500;0;;0;0;0;28.43507078730287;0;100;;true;true;1.3;-273.15
104;2500;0;;0;0;0;28.766300819862867;0;100;;true;true;1.3;-273.15
105;2500;0;;0;0;0;29.238940428459188;0;100;;true;true;1.3;-273.15
106;2500;0;;0;0;0;29.826187763611912;0;100;;true;true;1.3;-273.15
107;2500;0;;0;0;0;30.416678792013645;0;100;;true;true;1.3;-273.15
108;2500;0;;0;0;0;30.93449719349873;0;100;;true;true;1.3;-273.15
109;2500;0;;0;0;0;31.378977552402144;0;100;;true;true;1.3;-273.15
110;2500;0;;0;0;0;31.791569056366274;0;100;;true;true;1.3;-273.15
111;2500;0;;0;0;0;32.20744448398214;0;100;;true;true;1.3;-273.15
112;2500;0;;0;0;0;32.63582514088705;0;100;;true;true;1.3;-273.15
113;2500;0;;0;0;0;33.066854734517186;0;100;;true;true;1.3;-273.15
114;2500;0;;0;0;0;33.4873015260333;0;100;;true;true;1.3;-273.15
115;2500;0;;0;0;0;33.89075690798153;0;100;;true;true;1.3;-273.15
116;2500;0;;0;0;0;34.27869839911932;0;100;;true;true;1.3;-273.15
117;2500;0;;0;0;0;34.655818585625106;0;100;;true;true;1.3;-273.15
118;2500;0;;0;0;0;35.02561544729225;0;100;;true;true;1.3;-273.15
119;2500;0;;0;0;0;35.388909627954625;0;100;;true;true;1.3;-273.15
120;2500;0;;0;0;0;35.74502321074434;0;100;;true;true;1.3;-273.15
121;2500;0;;0;0;0;36.09293697843595;0;100;;true;true;1.3;-273.15
122;2500;0;;0;0;0;36.43228444655698;0;100;;true;true;1.3;-273.15
123;2500;0;;0;0;0;36.76336621134561;0;100;;true;true;1.3;-273.15
124;2500;0;;0;0;0;37.08671503985034;0;100;;true;true;1.3;-273.15
125;2500;0;;0;0;0;37.402875476819325;0;100;;true;true;1.3;-273.15
126;2500;0;;0;0;0;37.71196527522318;0;100;;true;true;1.3;-273.15
127;2500;0;;0;0;0;38.01403301028499;0;100;;true;true;1.3;-273.15
128;2500;0;;0;0;0;38.30925145649759;0;100;;true;true;1.3;-273.15
129;2500;0;;0;0;0;38.597710242154584;0;100;;true;true;1.3;-273.15
130;2400;0;;0;0;0;38.87844861016845;0;100;;true;true;1.3;-273.15
131;2400;0;;0;0;0;38.98786485917729;0;100;;true;true;1.3;-273.15
132;2400;0;;0;0;0;38.99950222665199;0;100;;true;true;1.3;-273.15
133;2400;0;;0;0;0;39.0565015612041;0;100;;true;true;1.3;-273.15
134;2400;0;;0;0;0;39.206226964219695;0;100;;true;true;1.3;-273.15
135;2400;0;;0;0;0;39.416447801063406;0;100;;true;true;1.3;-273.15
136;2400;0;;0;0;0;39.639106867404074;0;100;;true;true;1.3;-273.15
137;2400;0;;0;0;0;39.84301908272031;0;100;;true;true;1.3;-273.15
138;2400;0;;0;0;0;40.021297184999845;0;100;;true;true;1.3;-273.15
139;2400;0;;0;0;0;40.18271973581835;0;100;;true;true;1.3;-273.15
140;2400;0;;0;0;0;40.33824202260388;0;100;;true;true;1.3;-273.15
141;2400;0;;0;0;0;40.49471813807052;0;100;;true;true;1.3;-273.15
142;2400;0;;0;0;0;40.65353955792768;0;100;;true;true;1.3;-273.15
143;2400;0;;0;0;0;40.81291096394374;0;100;;true;true;1.3;-273.15

Flow sweep with 1.55 sg (using Matlab)-simulation-sequence

144;2400;0;;0;0;0;40.97014945270595;0;100;;true>true;1.3;-273.15
145;2400;0;;0;0;0;41.12365252941621;0;100;;true>true;1.3;-273.15
146;2400;0;;0;0;0;41.27306810786455;0;100;;true>true;1.3;-273.15
147;2400;0;;0;0;0;41.418891411694894;0;100;;true>true;1.3;-273.15
148;2400;0;;0;0;0;41.561741634367785;0;100;;true>true;1.3;-273.15
149;2400;0;;0;0;0;41.70197526883735;0;100;;true>true;1.3;-273.15
150;2400;0;;0;0;0;41.83967810443452;0;100;;true>true;1.3;-273.15
151;2400;0;;0;0;0;41.97469407786969;0;100;;true>true;1.3;-273.15
152;2400;0;;0;0;0;42.10689809871582;0;100;;true>true;1.3;-273.15
153;2400;0;;0;0;0;42.23633788891093;0;100;;true>true;1.3;-273.15
154;2400;0;;0;0;0;42.36314086499442;0;100;;true>true;1.3;-273.15
155;2400;0;;0;0;0;42.48739130751734;0;100;;true>true;1.3;-273.15
156;2400;0;;0;0;0;42.609090174836595;0;100;;true>true;1.3;-273.15
157;2400;0;;0;0;0;42.72825065767724;0;100;;true>true;1.3;-273.15
158;2400;0;;0;0;0;42.84490782236991;0;100;;true>true;1.3;-273.15
159;2400;0;;0;0;0;42.95910719984899;0;100;;true>true;1.3;-273.15
160;2300;0;;0;0;0;43.07091057709933;0;100;;true>true;1.3;-273.15
161;2300;0;;0;0;0;43.01356838205468;0;100;;true>true;1.3;-273.15
162;2300;0;;0;0;0;42.85551742984221;0;100;;true>true;1.3;-273.15
163;2300;0;;0;0;0;42.73917752403302;0;100;;true>true;1.3;-273.15
164;2300;0;;0;0;0;42.71727430512687;0;100;;true>true;1.3;-273.15
165;2300;0;;0;0;0;42.764697788892356;0;100;;true>true;1.3;-273.15
166;2300;0;;0;0;0;42.83446991485778;0;100;;true>true;1.3;-273.15
167;2300;0;;0;0;0;42.89454550894466;0;100;;true>true;1.3;-273.15
168;2300;0;;0;0;0;42.93422971695882;0;100;;true>true;1.3;-273.15
169;2300;0;;0;0;0;42.95800614931948;0;100;;true>true;1.3;-273.15
170;2300;0;;0;0;0;42.97718232054679;0;100;;true>true;1.3;-273.15
171;2300;0;;0;0;0;42.99740869641847;0;100;;true>true;1.3;-273.15
172;2300;0;;0;0;0;43.0207870748273;0;100;;true>true;1.3;-273.15
173;2300;0;;0;0;0;43.046800256803294;0;100;;true>true;1.3;-273.15
174;2300;0;;0;0;0;43.07379693370443;0;100;;true>true;1.3;-273.15
175;2300;0;;0;0;0;43.100324342233975;0;100;;true>true;1.3;-273.15
176;2300;0;;0;0;0;43.12578809640145;0;100;;true>true;1.3;-273.15
177;2300;0;;0;0;0;43.15022506352914;0;100;;true>true;1.3;-273.15
178;2300;0;;0;0;0;43.17392118822709;0;100;;true>true;1.3;-273.15
179;2300;0;;0;0;0;43.19711439660321;0;100;;true>true;1.3;-273.15
180;2300;0;;0;0;0;43.219893807718066;0;100;;true>true;1.3;-273.15
181;2300;0;;0;0;0;43.24386764814541;0;100;;true>true;1.3;-273.15
182;2300;0;;0;0;0;43.26695228971128;0;100;;true>true;1.3;-273.15
183;2300;0;;0;0;0;43.28849953090203;0;100;;true>true;1.3;-273.15
184;2300;0;;0;0;0;43.30877228877769;0;100;;true>true;1.3;-273.15
185;2300;0;;0;0;0;43.32820878477334;0;100;;true>true;1.3;-273.15
186;2300;0;;0;0;0;43.34708263299263;0;100;;true>true;1.3;-273.15
187;2300;0;;0;0;0;43.365586088850854;0;100;;true>true;1.3;-273.15
188;2300;0;;0;0;0;43.38372142136564;0;100;;true>true;1.3;-273.15
189;2300;0;;0;0;0;43.40136146917768;0;100;;true>true;1.3;-273.15
190;2200;0;;0;0;0;43.41837731791356;0;100;;true>true;1.3;-273.15
191;2200;0;;0;0;0;43.267318057851625;0;100;;true>true;1.3;-273.15

Flow sweep with 1.55 sg (using Matlab)-simulation-sequence

192;2200;0;;0;0;0;43.01195223076862;0;100;;true>true;1.3;-273.15
193;2200;0;;0;0;0;42.79961959776329;0;100;;true>true;1.3;-273.15
194;2200;0;;0;0;0;42.68698096576855;0;100;;true>true;1.3;-273.15
195;2200;0;;0;0;0;42.64515977430894;0;100;;true>true;1.3;-273.15
196;2200;0;;0;0;0;42.62660257245717;0;100;;true>true;1.3;-273.15
197;2200;0;;0;0;0;42.599775975624404;0;100;;true>true;1.3;-273.15
198;2200;0;;0;0;0;42.554321899854735;0;100;;true>true;1.3;-273.15
199;2200;0;;0;0;0;42.494645134746875;0;100;;true>true;1.3;-273.15
200;2200;0;;0;0;0;42.430133899984796;0;100;;true>true;1.3;-273.15
201;2200;0;;0;0;0;42.368288465707884;0;100;;true>true;1.3;-273.15
202;2200;0;;0;0;0;42.311965123768914;0;100;;true>true;1.3;-273.15
203;2200;0;;0;0;0;42.260482541020814;0;100;;true>true;1.3;-273.15
204;2200;0;;0;0;0;42.21175735860177;0;100;;true>true;1.3;-273.15
205;2200;0;;0;0;0;42.1639518060345;0;100;;true>true;1.3;-273.15
206;2200;0;;0;0;0;42.11618776447843;0;100;;true>true;1.3;-273.15
207;2200;0;;0;0;0;42.06842941588383;0;100;;true>true;1.3;-273.15
208;2200;0;;0;0;0;42.021027438987055;0;100;;true>true;1.3;-273.15
209;2200;0;;0;0;0;41.974327432743415;0;100;;true>true;1.3;-273.15
210;2200;0;;0;0;0;41.928411575569854;0;100;;true>true;1.3;-273.15
211;2200;0;;0;0;0;41.883274868113034;0;100;;true>true;1.3;-273.15
212;2200;0;;0;0;0;41.83886417884477;0;100;;true>true;1.3;-273.15
213;2200;0;;0;0;0;41.79510561283972;0;100;;true>true;1.3;-273.15
214;2200;0;;0;0;0;41.751933981660514;0;100;;true>true;1.3;-273.15
215;2200;0;;0;0;0;41.70930422162479;0;100;;true>true;1.3;-273.15
216;2200;0;;0;0;0;41.66719560857825;0;100;;true>true;1.3;-273.15
217;2200;0;;0;0;0;41.625593832764366;0;100;;true>true;1.3;-273.15
218;2200;0;;0;0;0;41.5845020139051;0;100;;true>true;1.3;-273.15
219;2200;0;;0;0;0;41.544046388802;0;100;;true>true;1.3;-273.15
220;2100;0;;0;0;0;41.50421963745543;0;100;;true>true;1.3;-273.15
221;2100;0;;0;0;0;41.29627850071097;0;100;;true>true;1.3;-273.15
222;2100;0;;0;0;0;40.98160061423614;0;100;;true>true;1.3;-273.15
223;2100;0;;0;0;0;40.70800446589794;0;100;;true>true;1.3;-273.15
224;2100;0;;0;0;0;40.535283576836214;0;100;;true>true;1.3;-273.15
225;2100;0;;0;0;0;40.439610236557264;0;100;;true>true;1.3;-273.15
226;2100;0;;0;0;0;40.37419984107529;0;100;;true>true;1.3;-273.15
227;2100;0;;0;0;0;40.30360998133424;0;100;;true>true;1.3;-273.15
228;2100;0;;0;0;0;40.21470424374043;0;100;;true>true;1.3;-273.15
229;2100;0;;0;0;0;40.11106731237153;0;100;;true>true;1.3;-273.15
230;2100;0;;0;0;0;40.00248302011973;0;100;;true>true;1.3;-273.15
231;2100;0;;0;0;0;39.89709743999105;0;100;;true>true;1.3;-273.15
232;2100;0;;0;0;0;39.79835242419818;0;100;;true>true;1.3;-273.15
233;2100;0;;0;0;0;39.70573952993974;0;100;;true>true;1.3;-273.15
234;2100;0;;0;0;0;39.61704210300383;0;100;;true>true;1.3;-273.15
235;2100;0;;0;0;0;39.530251623776074;0;100;;true>true;1.3;-273.15
236;2100;0;;0;0;0;39.4444340207152;0;100;;true>true;1.3;-273.15
237;2100;0;;0;0;0;39.359530669641714;0;100;;true>true;1.3;-273.15
238;2100;0;;0;0;0;39.275861833663065;0;100;;true>true;1.3;-273.15
239;2100;0;;0;0;0;39.19375079625807;0;100;;true>true;1.3;-273.15

Flow sweep with 1.55 sg (using Matlab)-simulation-sequence

240;2100;0;;0;0;0;39.11334147370551;0;100;;true>true;1.3;-273.15
241;2100;0;;0;0;0;39.034607401093055;0;100;;true>true;1.3;-273.15
242;2100;0;;0;0;0;38.957421327328966;0;100;;true>true;1.3;-273.15
243;2100;0;;0;0;0;38.88167025825765;0;100;;true>true;1.3;-273.15
244;2100;0;;0;0;0;38.80726789101891;0;100;;true>true;1.3;-273.15
245;2100;0;;0;0;0;38.734167642714176;0;100;;true>true;1.3;-273.15
246;2100;0;;0;0;0;38.66236379868101;0;100;;true>true;1.3;-273.15
247;2100;0;;0;0;0;38.591833127424316;0;100;;true>true;1.3;-273.15
248;2100;0;;0;0;0;38.522536607148425;0;100;;true>true;1.3;-273.15
249;2100;0;;0;0;0;38.454524721035895;0;100;;true>true;1.3;-273.15
250;2000;0;;0;0;0;38.387708527301655;0;100;;true>true;1.3;-273.15
251;2000;0;;0;0;0;38.15089186001222;0;100;;true>true;1.3;-273.15
252;2000;0;;0;0;0;37.80848387148265;0;100;;true>true;1.3;-273.15
253;2000;0;;0;0;0;37.513733951258445;0;100;;true>true;1.3;-273.15
254;2000;0;;0;0;0;37.32764461373786;0;100;;true>true;1.3;-273.15
255;2000;0;;0;0;0;37.22170997874893;0;100;;true>true;1.3;-273.15
256;2000;0;;0;0;0;37.14377659879731;0;100;;true>true;1.3;-273.15
257;2000;0;;0;0;0;37.05746021812309;0;100;;true>true;1.3;-273.15
258;2000;0;;0;0;0;36.950988759569796;0;100;;true>true;1.3;-273.15
259;2000;0;;0;0;0;36.829909381757076;0;100;;true>true;1.3;-273.15
260;2000;0;;0;0;0;36.70525557423419;0;100;;true>true;1.3;-273.15
261;2000;0;;0;0;0;36.5855437736393;0;100;;true>true;1.3;-273.15
262;2000;0;;0;0;0;36.47360665759476;0;100;;true>true;1.3;-273.15
263;2000;0;;0;0;0;36.368470729883896;0;100;;true>true;1.3;-273.15
264;2000;0;;0;0;0;36.26755375055066;0;100;;true>true;1.3;-273.15
265;2000;0;;0;0;0;36.16878967225604;0;100;;true>true;1.3;-273.15
266;2000;0;;0;0;0;36.07135826169293;0;100;;true>true;1.3;-273.15
267;2000;0;;0;0;0;35.97537583005203;0;100;;true>true;1.3;-273.15
268;2000;0;;0;0;0;35.88132036941445;0;100;;true>true;1.3;-273.15
269;2000;0;;0;0;0;35.7896176584924;0;100;;true>true;1.3;-273.15
270;2000;0;;0;0;0;35.7003364002158;0;100;;true>true;1.3;-273.15
271;2000;0;;0;0;0;35.6132910301835;0;100;;true>true;1.3;-273.15
272;2000;0;;0;0;0;35.52825287732554;0;100;;true>true;1.3;-273.15
273;2000;0;;0;0;0;35.445064197632156;0;100;;true>true;1.3;-273.15
274;2000;0;;0;0;0;35.36360599742404;0;100;;true>true;1.3;-273.15
275;2000;0;;0;0;0;35.28387075656019;0;100;;true>true;1.3;-273.15
276;2000;0;;0;0;0;35.205901591451244;0;100;;true>true;1.3;-273.15
277;2000;0;;0;0;0;35.12970807102531;0;100;;true>true;1.3;-273.15
278;2000;0;;0;0;0;35.05526157103089;0;100;;true>true;1.3;-273.15
279;2000;0;;0;0;0;34.98250009470837;0;100;;true>true;1.3;-273.15
280;1900.0000000000002;0;;0;0;0;34.911378948732185;0;100;;true>true;1.3;-
273.15
281;1900.0000000000002;0;;0;0;0;34.66857342339387;0;100;;true>true;1.3;-
273.15
282;1900.0000000000002;0;;0;0;0;34.31786013230991;0;100;;true>true;1.3;-
273.15
283;1900.0000000000002;0;;0;0;0;34.017837479111286;0;100;;true>true;1.3;-
273.15

Flow sweep with 1.55 sg (using Matlab)-simulation-sequence

284;1900.0000000000002;0;;0;0;33.83234900329696;0;100;;true>true;1.3;-
273.15
285;1900.0000000000002;0;;0;0;33.729657168921285;0;100;;true>true;1.3;-
273.15
286;1900.0000000000002;0;;0;0;33.65320925272314;0;100;;true>true;1.3;-
273.15
287;1900.0000000000002;0;;0;0;33.56493849772495;0;100;;true>true;1.3;-
273.15
288;1900.0000000000002;0;;0;0;33.454337308402394;0;100;;true>true;1.3;-
273.15
289;1900.0000000000002;0;;0;0;33.32925370524938;0;100;;true>true;1.3;-
273.15
290;1900.0000000000002;0;;0;0;33.20246410281133;0;100;;true>true;1.3;-
273.15
291;1900.0000000000002;0;;0;0;33.08285601909813;0;100;;true>true;1.3;-
273.15
292;1900.0000000000002;0;;0;0;32.97271011161851;0;100;;true>true;1.3;-
273.15
293;1900.0000000000002;0;;0;0;32.86993939804867;0;100;;true>true;1.3;-
273.15
294;1900.0000000000002;0;;0;0;32.77141964674428;0;100;;true>true;1.3;-
273.15
295;1900.0000000000002;0;;0;0;32.67505141522672;0;100;;true>true;1.3;-
273.15
296;1900.0000000000002;0;;0;0;32.58025593364405;0;100;;true>true;1.3;-
273.15
297;1900.0000000000002;0;;0;0;32.48737192404765;0;100;;true>true;1.3;-
273.15
298;1900.0000000000002;0;;0;0;32.39695938990206;0;100;;true>true;1.3;-
273.15
299;1900.0000000000002;0;;0;0;32.30935500390795;0;100;;true>true;1.3;-
273.15
300;1900.0000000000002;0;;0;0;32.22451665754007;0;100;;true>true;1.3;-
273.15
301;1900.0000000000002;0;;0;0;32.14219878561646;0;100;;true>true;1.3;-
273.15
302;1900.0000000000002;0;;0;0;32.06218014956177;0;100;;true>true;1.3;-
273.15
303;1900.0000000000002;0;;0;0;31.984422596415474;0;100;;true>true;1.3;-
273.15
304;1900.0000000000002;0;;0;0;31.908844685903194;0;100;;true>true;1.3;-
273.15
305;1900.0000000000002;0;;0;0;31.835341105959454;0;100;;true>true;1.3;-
273.15
306;1900.0000000000002;0;;0;0;31.763816270844398;0;100;;true>true;1.3;-
273.15
307;1900.0000000000002;0;;0;0;31.694211277253913;0;100;;true>true;1.3;-
273.15
308;1900.0000000000002;0;;0;0;31.626483144150868;0;100;;true>true;1.3;-
273.15

Flow sweep with 1.55 sg (using Matlab)-simulation-sequence

309;1900.0000000000002;0;;0;0;0;31.56059442307977;0;100;;true;true;1.3;-273.15
310;1800;0;;0;0;0;31.496500055973875;0;100;;true;true;1.3;-273.15
311;1800;0;;0;0;0;31.257262576578533;0;100;;true;true;1.3;-273.15
312;1800;0;;0;0;0;30.907087463256204;0;100;;true;true;1.3;-273.15
313;1800;0;;0;0;0;30.611119845821772;0;100;;true;true;1.3;-273.15
314;1800;0;;0;0;0;30.436343121027598;0;100;;true;true;1.3;-273.15
315;1800;0;;0;0;0;30.347207918284614;0;100;;true;true;1.3;-273.15
316;1800;0;;0;0;0;30.281767175800102;0;100;;true;true;1.3;-273.15
317;1800;0;;0;0;0;30.199995529008174;0;100;;true;true;1.3;-273.15
318;1800;0;;0;0;0;30.09319514121291;0;100;;true;true;1.3;-273.15
319;1800;0;;0;0;0;29.97234267150014;0;100;;true;true;1.3;-273.15
320;1800;0;;0;0;0;29.852334894592026;0;100;;true;true;1.3;-273.15
321;1800;0;;0;0;0;29.742099297554496;0;100;;true;true;1.3;-273.15
322;1800;0;;0;0;0;29.64287196502325;0;100;;true;true;1.3;-273.15
323;1800;0;;0;0;0;29.551313154420473;0;100;;true;true;1.3;-273.15
324;1800;0;;0;0;0;29.463521133673748;0;100;;true;true;1.3;-273.15
325;1800;0;;0;0;0;29.377498260960493;0;100;;true;true;1.3;-273.15
326;1800;0;;0;0;0;29.292970747630488;0;100;;true;true;1.3;-273.15
327;1800;0;;0;0;0;29.210674398706953;0;100;;true;true;1.3;-273.15
328;1800;0;;0;0;0;29.13125035068362;0;100;;true;true;1.3;-273.15
329;1800;0;;0;0;0;29.05494043528069;0;100;;true;true;1.3;-273.15
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331;1800;0;;0;0;0;28.910859649368348;0;100;;true;true;1.3;-273.15
332;1800;0;;0;0;0;28.84249598948434;0;100;;true;true;1.3;-273.15
333;1800;0;;0;0;0;28.776341189606125;0;100;;true;true;1.3;-273.15
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335;1800;0;;0;0;0;28.650377781977397;0;100;;true;true;1.3;-273.15
336;1800;0;;0;0;0;28.590485687454496;0;100;;true;true;1.3;-273.15
337;1800;0;;0;0;0;28.532570574548586;0;100;;true;true;1.3;-273.15
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352;1700;0;;0;0;0;26.674317001541997;0;100;;true;true;1.3;-273.15
353;1700;0;;0;0;0;26.59770328832186;0;100;;true;true;1.3;-273.15
354;1700;0;;0;0;0;26.52402609265776;0;100;;true;true;1.3;-273.15
355;1700;0;;0;0;0;26.451344311991775;0;100;;true;true;1.3;-273.15
356;1700;0;;0;0;0;26.380008225693118;0;100;;true;true;1.3;-273.15

Flow sweep with 1.55 sg (using Matlab)-simulation-sequence

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359;1700;0;;0;0;0;26.183674673940764;0;100;;true>true;1.3;-273.15
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363;1700;0;;0;0;0;25.9594422964061;0;100;;true>true;1.3;-273.15
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367;1700;0;;0;0;0;25.767480146616577;0;100;;true>true;1.3;-273.15
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370;1600;0;;0;0;0;25.641815354569335;0;100;;true>true;1.3;-273.15
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392;1600;0;;0;0;0;23.551048341038594;0;100;;true>true;1.3;-273.15
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394;1600;0;;0;0;0;23.468936743362462;0;100;;true>true;1.3;-273.15
395;1600;0;;0;0;0;23.430755986777406;0;100;;true>true;1.3;-273.15
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397;1600;0;;0;0;0;23.359605814442034;0;100;;true>true;1.3;-273.15
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399;1600;0;;0;0;0;23.294301513065587;0;100;;true>true;1.3;-273.15
400;1500;0;;0;0;0;23.26367904489875;0;100;;true>true;1.3;-273.15
401;1500;0;;0;0;0;23.043310802115023;0;100;;true>true;1.3;-273.15
402;1500;0;;0;0;0;22.706948963467035;0;100;;true>true;1.3;-273.15
403;1500;0;;0;0;0;22.445594058961;0;100;;true>true;1.3;-273.15
404;1500;0;;0;0;0;22.330181234855704;0;100;;true>true;1.3;-273.15

Flow sweep with 1.55 sg (using Matlab)-simulation-sequence

405;1500;0;;0;0;0;22.305501117985678;0;100;;true>true;1.3;-273.15
406;1500;0;;0;0;0;22.28873761902563;0;100;;true>true;1.3;-273.15
407;1500;0;;0;0;0;22.23456566115461;0;100;;true>true;1.3;-273.15
408;1500;0;;0;0;0;22.14415432019056;0;100;;true>true;1.3;-273.15
409;1500;0;;0;0;0;22.042110950159802;0;100;;true>true;1.3;-273.15
410;1500;0;;0;0;0;21.950655242016946;0;100;;true>true;1.3;-273.15
411;1500;0;;0;0;0;21.877543985162124;0;100;;true>true;1.3;-273.15
412;1500;0;;0;0;0;21.818362996317273;0;100;;true>true;1.3;-273.15
413;1500;0;;0;0;0;21.764916962572862;0;100;;true>true;1.3;-273.15
414;1500;0;;0;0;0;21.71188198569606;0;100;;true>true;1.3;-273.15
415;1500;0;;0;0;0;21.65845933141298;0;100;;true>true;1.3;-273.15
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419;1500;0;;0;0;0;21.47102580878212;0;100;;true>true;1.3;-273.15
420;1500;0;;0;0;0;21.431882250107602;0;100;;true>true;1.3;-273.15
421;1500;0;;0;0;0;21.394549797062243;0;100;;true>true;1.3;-273.15
422;1500;0;;0;0;0;21.358822035385327;0;100;;true>true;1.3;-273.15
423;1500;0;;0;0;0;21.324765377358563;0;100;;true>true;1.3;-273.15
424;1500;0;;0;0;0;21.292469688828472;0;100;;true>true;1.3;-273.15
425;1500;0;;0;0;0;21.261913284508136;0;100;;true>true;1.3;-273.15
426;1500;0;;0;0;0;21.232967548341637;0;100;;true>true;1.3;-273.15
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429;1500;0;;0;0;0;21.154303921807834;0;100;;true>true;1.3;-273.15
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431;1500;0;;0;0;0;21.107901854191798;0;100;;true>true;1.3;-273.15
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433;1500;0;;0;0;0;21.065835758279356;0;100;;true>true;1.3;-273.15
434;1500;0;;0;0;0;21.046245815506794;0;100;;true>true;1.3;-273.15
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451;1500;0;;0;0;0;20.821389563192533;0;100;;true>true;1.3;-273.15
452;1500;0;;0;0;0;20.81267283247037;0;100;;true>true;1.3;-273.15

Flow sweep with 1.55 sg (using Matlab)-simulation-sequence

453;1500;0;;0;0;0;20.804315639900192;0;100;;true>true;1.3;-273.15
454;1500;0;;0;0;0;20.79630273362673;0;100;;true>true;1.3;-273.15
455;1500;0;;0;0;0;20.788677729594195;0;100;;true>true;1.3;-273.15
456;1500;0;;0;0;0;20.78147037267372;0;100;;true>true;1.3;-273.15
457;1500;0;;0;0;0;20.774645260514525;0;100;;true>true;1.3;-273.15
458;1500;0;;0;0;0;20.768077614288092;0;100;;true>true;1.3;-273.15
459;1500;0;;0;0;0;20.76166962588905;0;100;;true>true;1.3;-273.15
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461;1600;0;;0;0;0;20.94737196074494;0;100;;true>true;1.3;-273.15
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464;1600;0;;0;0;0;21.542177706651337;0;100;;true>true;1.3;-273.15
465;1600;0;;0;0;0;21.52455004455665;0;100;;true>true;1.3;-273.15
466;1600;0;;0;0;0;21.50897104524892;0;100;;true>true;1.3;-273.15
467;1600;0;;0;0;0;21.5400152175393;0;100;;true>true;1.3;-273.15
468;1600;0;;0;0;0;21.610990222097854;0;100;;true>true;1.3;-273.15
469;1600;0;;0;0;0;21.69135378965795;0;100;;true>true;1.3;-273.15
470;1600;0;;0;0;0;21.756783061835883;0;100;;true>true;1.3;-273.15
471;1600;0;;0;0;0;21.80151706436046;0;100;;true>true;1.3;-273.15
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473;1600;0;;0;0;0;21.86222303288224;0;100;;true>true;1.3;-273.15
474;1600;0;;0;0;0;21.89367040143042;0;100;;true>true;1.3;-273.15
475;1600;0;;0;0;0;21.92718525434665;0;100;;true>true;1.3;-273.15
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477;1600;0;;0;0;0;21.988837529128812;0;100;;true>true;1.3;-273.15
478;1600;0;;0;0;0;22.014245146428618;0;100;;true>true;1.3;-273.15
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481;1600;0;;0;0;0;22.078931138056106;0;100;;true>true;1.3;-273.15
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498;1700;0;;0;0;0;23.177848198733102;0;100;;true>true;1.3;-273.15
499;1700;0;;0;0;0;23.267250646977182;0;100;;true>true;1.3;-273.15
500;1700;0;;0;0;0;23.34315808884578;0;100;;true>true;1.3;-273.15

Flow sweep with 1.55 sg (using Matlab)-simulation-sequence

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503;1700;0;;0;0;0;23.48392418343996;0;100;;true>true;1.3;-273.15
504;1700;0;;0;0;0;23.525702878290012;0;100;;true>true;1.3;-273.15
505;1700;0;;0;0;0;23.56872133232148;0;100;;true>true;1.3;-273.15
506;1700;0;;0;0;0;23.610488100109823;0;100;;true>true;1.3;-273.15
507;1700;0;;0;0;0;23.64894358799561;0;100;;true>true;1.3;-273.15
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509;1700;0;;0;0;0;23.715462927264284;0;100;;true>true;1.3;-273.15
510;1700;0;;0;0;0;23.745446748586758;0;100;;true>true;1.3;-273.15
511;1700;0;;0;0;0;23.774266786702395;0;100;;true>true;1.3;-273.15
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514;1700;0;;0;0;0;23.853838374218768;0;100;;true>true;1.3;-273.15
515;1700;0;;0;0;0;23.877375845376534;0;100;;true>true;1.3;-273.15
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523;1800;0;;0;0;0;24.72384245299475;0;100;;true>true;1.3;-273.15
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527;1800;0;;0;0;0;24.892501849357153;0;100;;true>true;1.3;-273.15
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530;1800;0;;0;0;0;25.14548722024919;0;100;;true>true;1.3;-273.15
531;1800;0;;0;0;0;25.208369527112524;0;100;;true>true;1.3;-273.15
532;1800;0;;0;0;0;25.258875252956187;0;100;;true>true;1.3;-273.15
533;1800;0;;0;0;0;25.30502256642514;0;100;;true>true;1.3;-273.15
534;1800;0;;0;0;0;25.351637440943602;0;100;;true>true;1.3;-273.15
535;1800;0;;0;0;0;25.399063457747374;0;100;;true>true;1.3;-273.15
536;1800;0;;0;0;0;25.445343503358416;0;100;;true>true;1.3;-273.15
537;1800;0;;0;0;0;25.488638830014953;0;100;;true>true;1.3;-273.15
538;1800;0;;0;0;0;25.52845131221807;0;100;;true>true;1.3;-273.15
539;1800;0;;0;0;0;25.56535349759311;0;100;;true>true;1.3;-273.15
540;1800;0;;0;0;0;25.60025046797397;0;100;;true>true;1.3;-273.15
541;1800;0;;0;0;0;25.63368383075598;0;100;;true>true;1.3;-273.15
542;1800;0;;0;0;0;25.66581004662169;0;100;;true>true;1.3;-273.15
543;1800;0;;0;0;0;25.696543596127924;0;100;;true>true;1.3;-273.15
544;1800;0;;0;0;0;25.72579769609302;0;100;;true>true;1.3;-273.15
545;1800;0;;0;0;0;25.753607595292884;0;100;;true>true;1.3;-273.15
546;1800;0;;0;0;0;25.780159849446505;0;100;;true>true;1.3;-273.15
547;1800;0;;0;0;0;25.80548727901694;0;100;;true>true;1.3;-273.15
548;1800;0;;0;0;0;25.82962264433832;0;100;;true>true;1.3;-273.15

Flow sweep with 1.55 sg (using Matlab)-simulation-sequence

549;1800;0;;0;0;0;25.85268775242059;0;100;;true;true;1.3;-273.15
550;1900.00000000000002;0;;0;0;0;25.874716045054914;0;100;;true;true;1.3;-
273.15
551;1900.00000000000002;0;;0;0;0;26.08260520830517;0;100;;true;true;1.3;-
273.15
552;1900.00000000000002;0;;0;0;0;26.38580332722106;0;100;;true;true;1.3;-
273.15
553;1900.00000000000002;0;;0;0;0;26.619066471428273;0;100;;true;true;1.3;-
273.15
554;1900.00000000000002;0;;0;0;0;26.721678198827227;0;100;;true;true;1.3;-
273.15
555;1900.00000000000002;0;;0;0;0;26.746284461752968;0;100;;true;true;1.3;-
273.15
556;1900.00000000000002;0;;0;0;0;26.765164229165272;0;100;;true;true;1.3;-
273.15
557;1900.00000000000002;0;;0;0;0;26.816184773716422;0;100;;true;true;1.3;-
273.15
558;1900.00000000000002;0;;0;0;0;26.897703072073398;0;100;;true;true;1.3;-
273.15
559;1900.00000000000002;0;;0;0;0;26.988857891259244;0;100;;true;true;1.3;-
273.15
560;1900.00000000000002;0;;0;0;0;27.071158083188724;0;100;;true;true;1.3;-
273.15
561;1900.00000000000002;0;;0;0;0;27.13826560861762;0;100;;true;true;1.3;-
273.15
562;1900.00000000000002;0;;0;0;0;27.193999883284693;0;100;;true;true;1.3;-
273.15
563;1900.00000000000002;0;;0;0;0;27.24514292362224;0;100;;true;true;1.3;-
273.15
564;1900.00000000000002;0;;0;0;0;27.295891927239797;0;100;;true;true;1.3;-
273.15
565;1900.00000000000002;0;;0;0;0;27.3468459488026;0;100;;true;true;1.3;-273.15
566;1900.00000000000002;0;;0;0;0;27.396580513253245;0;100;;true;true;1.3;-
273.15
567;1900.00000000000002;0;;0;0;0;27.443632391005462;0;100;;true;true;1.3;-
273.15
568;1900.00000000000002;0;;0;0;0;27.487539449701647;0;100;;true;true;1.3;-
273.15
569;1900.00000000000002;0;;0;0;0;27.528624755527314;0;100;;true;true;1.3;-
273.15
570;1900.00000000000002;0;;0;0;0;27.567604807221112;0;100;;true;true;1.3;-
273.15
571;1900.00000000000002;0;;0;0;0;27.604967422567718;0;100;;true;true;1.3;-
273.15
572;1900.00000000000002;0;;0;0;0;27.64089137706361;0;100;;true;true;1.3;-
273.15
573;1900.00000000000002;0;;0;0;0;27.67535676665382;0;100;;true;true;1.3;-
273.15
574;1900.00000000000002;0;;0;0;0;27.708284811971577;0;100;;true;true;1.3;-
273.15

Flow sweep with 1.55 sg (using Matlab)-simulation-sequence

575;1900.0000000000002;0;;0;0;27.739698210165297;0;100;;true>true;1.3;-273.15
576;1900.0000000000002;0;;0;0;27.769710551167304;0;100;;true>true;1.3;-273.15
577;1900.0000000000002;0;;0;0;27.79844341871228;0;100;;true>true;1.3;-273.15
578;1900.0000000000002;0;;0;0;27.826053270938335;0;100;;true>true;1.3;-273.15
579;1900.0000000000002;0;;0;0;27.852524512932238;0;100;;true>true;1.3;-273.15
580;2000;0;;0;0;27.877832580497824;0;100;;true>true;1.3;-273.15
581;2000;0;;0;0;28.086967276862886;0;100;;true>true;1.3;-273.15
582;2000;0;;0;0;28.38666888976154;0;100;;true>true;1.3;-273.15
583;2000;0;;0;0;28.61800895874267;0;100;;true>true;1.3;-273.15
584;2000;0;;0;0;28.72465181476948;0;100;;true>true;1.3;-273.15
585;2000;0;;0;0;28.75613552701849;0;100;;true>true;1.3;-273.15
586;2000;0;;0;0;28.780512214580106;0;100;;true>true;1.3;-273.15
587;2000;0;;0;0;28.83356044118573;0;100;;true>true;1.3;-273.15
588;2000;0;;0;0;28.914650117347833;0;100;;true>true;1.3;-273.15
589;2000;0;;0;0;29.00538057100243;0;100;;true>true;1.3;-273.15
590;2000;0;;0;0;29.08894259991363;0;100;;true>true;1.3;-273.15
591;2000;0;;0;0;29.159042921996516;0;100;;true>true;1.3;-273.15
592;2000;0;;0;0;29.218430149409453;0;100;;true>true;1.3;-273.15
593;2000;0;;0;0;29.272936122179296;0;100;;true>true;1.3;-273.15
594;2000;0;;0;0;29.32654350850005;0;100;;true>true;1.3;-273.15
595;2000;0;;0;0;29.380213521962762;0;100;;true>true;1.3;-273.15
596;2000;0;;0;0;29.43279426955541;0;100;;true>true;1.3;-273.15
597;2000;0;;0;0;29.48290178483824;0;100;;true>true;1.3;-273.15
598;2000;0;;0;0;29.529989491668683;0;100;;true>true;1.3;-273.15
599;2000;0;;0;0;29.574311387443487;0;100;;true>true;1.3;-273.15
600;2000;0;;0;0;29.616466316732133;0;100;;true>true;1.3;-273.15
601;2000;0;;0;0;29.65693346061624;0;100;;true>true;1.3;-273.15
602;2000;0;;0;0;29.69590418395427;0;100;;true>true;1.3;-273.15
603;2000;0;;0;0;29.73337811345001;0;100;;true>true;1.3;-273.15
604;2000;0;;0;0;29.76930033946167;0;100;;true>true;1.3;-273.15
605;2000;0;;0;0;29.803673375477715;0;100;;true>true;1.3;-273.15
606;2000;0;;0;0;29.836572087210868;0;100;;true>true;1.3;-273.15
607;2000;0;;0;0;29.868119088499785;0;100;;true>true;1.3;-273.15
608;2000;0;;0;0;29.898470950490186;0;100;;true>true;1.3;-273.15
609;2000;0;;0;0;29.92763906587996;0;100;;true>true;1.3;-273.15
610;2100;0;;0;0;29.955612825753253;0;100;;true>true;1.3;-273.15
611;2100;0;;0;0;30.16605861737938;0;100;;true>true;1.3;-273.15
612;2100;0;;0;0;30.46241253754294;0;100;;true>true;1.3;-273.15
613;2100;0;;0;0;30.69143920043618;0;100;;true>true;1.3;-273.15
614;2100;0;;0;0;30.80102894224519;0;100;;true>true;1.3;-273.15
615;2100;0;;0;0;30.839148893884527;0;100;;true>true;1.3;-273.15
616;2100;0;;0;0;30.868789544591657;0;100;;true>true;1.3;-273.15
617;2100;0;;0;0;30.923573840693958;0;100;;true>true;1.3;-273.15
618;2100;0;;0;0;31.00426134108239;0;100;;true>true;1.3;-273.15

Flow sweep with 1.55 sg (using Matlab)-simulation-sequence

619;2100;0;;0;0;0;31.09493785829942;0;100;;true>true;1.3;-273.15
620;2100;0;;0;0;0;31.18020820200231;0;100;;true>true;1.3;-273.15
621;2100;0;;0;0;0;31.25359406983591;0;100;;true>true;1.3;-273.15
622;2100;0;;0;0;0;31.316860725546803;0;100;;true>true;1.3;-273.15
623;2100;0;;0;0;0;31.375087212602498;0;100;;true>true;1.3;-273.15
624;2100;0;;0;0;0;31.43188063140105;0;100;;true>true;1.3;-273.15
625;2100;0;;0;0;0;31.48825025730228;0;100;;true>true;1.3;-273.15
626;2100;0;;0;0;0;31.543487762540188;0;100;;true>true;1.3;-273.15
627;2100;0;;0;0;0;31.596527955160386;0;100;;true>true;1.3;-273.15
628;2100;0;;0;0;0;31.64683985803558;0;100;;true>true;1.3;-273.15
629;2100;0;;0;0;0;31.69451559674729;0;100;;true>true;1.3;-273.15
630;2100;0;;0;0;0;31.739983792169408;0;100;;true>true;1.3;-273.15
631;2100;0;;0;0;0;31.783633457428913;0;100;;true>true;1.3;-273.15
632;2100;0;;0;0;0;31.825684753089806;0;100;;true>true;1.3;-273.15
633;2100;0;;0;0;0;31.866169674681586;0;100;;true>true;1.3;-273.15
634;2100;0;;0;0;0;31.905082374183625;0;100;;true>true;1.3;-273.15
635;2100;0;;0;0;0;31.94243298113507;0;100;;true>true;1.3;-273.15
636;2100;0;;0;0;0;31.9782559496274;0;100;;true>true;1.3;-273.15
637;2100;0;;0;0;0;32.012733814215025;0;100;;true>true;1.3;-273.15
638;2100;0;;0;0;0;32.04588420659329;0;100;;true>true;1.3;-273.15
639;2100;0;;0;0;0;32.077705463453526;0;100;;true>true;1.3;-273.15
640;2200;0;;0;0;0;32.10822291272057;0;100;;true>true;1.3;-273.15
641;2200;0;;0;0;0;32.320118792798766;0;100;;true>true;1.3;-273.15
642;2200;0;;0;0;0;32.61417273300944;0;100;;true>true;1.3;-273.15
643;2200;0;;0;0;0;32.842950577617536;0;100;;true>true;1.3;-273.15
644;2200;0;;0;0;0;32.95849239433564;0;100;;true>true;1.3;-273.15
645;2200;0;;0;0;0;33.00609109124394;0;100;;true>true;1.3;-273.15
646;2200;0;;0;0;0;33.04372799909617;0;100;;true>true;1.3;-273.15
647;2200;0;;0;0;0;33.10280139070755;0;100;;true>true;1.3;-273.15
648;2200;0;;0;0;0;33.18518761519994;0;100;;true>true;1.3;-273.15
649;2200;0;;0;0;0;33.27734288166692;0;100;;true>true;1.3;-273.15
650;2200;0;;0;0;0;33.36556219194982;0;100;;true>true;1.3;-273.15
651;2200;0;;0;0;0;33.443384568882905;0;100;;true>true;1.3;-273.15
652;2200;0;;0;0;0;33.51156056882796;0;100;;true>true;1.3;-273.15
653;2200;0;;0;0;0;33.574094673094905;0;100;;true>true;1.3;-273.15
654;2200;0;;0;0;0;33.63448441361681;0;100;;true>true;1.3;-273.15
655;2200;0;;0;0;0;33.6942772384275;0;100;;true>true;1.3;-273.15
656;2200;0;;0;0;0;33.753089816239005;0;100;;true>true;1.3;-273.15
657;2200;0;;0;0;0;33.809814437783345;0;100;;true>true;1.3;-273.15
658;2200;0;;0;0;0;33.86387421307212;0;100;;true>true;1.3;-273.15
659;2200;0;;0;0;0;33.91524928765091;0;100;;true>true;1.3;-273.15
660;2200;0;;0;0;0;33.96427716035756;0;100;;true>true;1.3;-273.15
661;2200;0;;0;0;0;34.011336922033614;0;100;;true>true;1.3;-273.15
662;2200;0;;0;0;0;34.05665453302556;0;100;;true>true;1.3;-273.15
663;2200;0;;0;0;0;34.10029452318579;0;100;;true>true;1.3;-273.15
664;2200;0;;0;0;0;34.142288580112584;0;100;;true>true;1.3;-273.15
665;2200;0;;0;0;0;34.182642921429505;0;100;;true>true;1.3;-273.15
666;2200;0;;0;0;0;34.221367092945464;0;100;;true>true;1.3;-273.15

Flow sweep with 1.55 sg (using Matlab)-simulation-sequence

667;2200;0;;0;0;0;34.25851605343581;0;100;;true;true;1.3;-273.15
668;2200;0;;0;0;0;34.294126761111734;0;100;;true;true;1.3;-273.15
669;2200;0;;0;0;0;34.32827283649665;0;100;;true;true;1.3;-273.15
670;2300;0;;0;0;0;34.36100811354407;0;100;;true;true;1.3;-273.15
671;2300;0;;0;0;0;34.57492389818186;0;100;;true;true;1.3;-273.15
672;2300;0;;0;0;0;34.868378296302325;0;100;;true;true;1.3;-273.15
673;2300;0;;0;0;0;35.09929136676506;0;100;;true;true;1.3;-273.15
674;2300;0;;0;0;0;35.22146074544321;0;100;;true;true;1.3;-273.15
675;2300;0;;0;0;0;35.27678377703905;0;100;;true;true;1.3;-273.15
676;2300;0;;0;0;0;35.31962793838862;0;100;;true;true;1.3;-273.15
677;2300;0;;0;0;0;35.38055939845943;0;100;;true;true;1.3;-273.15
678;2300;0;;0;0;0;35.46293215724397;0;100;;true;true;1.3;-273.15
679;2300;0;;0;0;0;35.55493351760573;0;100;;true;true;1.3;-273.15
680;2300;0;;0;0;0;35.64374473835997;0;100;;true;true;1.3;-273.15
681;2300;0;;0;0;0;35.72319867719402;0;100;;true;true;1.3;-273.15
682;2300;0;;0;0;0;35.79347130716409;0;100;;true;true;1.3;-273.15
683;2300;0;;0;0;0;35.85799147361624;0;100;;true;true;1.3;-273.15
684;2300;0;;0;0;0;35.919937831196584;0;100;;true;true;1.3;-273.15
685;2300;0;;0;0;0;35.980718660273226;0;100;;true;true;1.3;-273.15
686;2300;0;;0;0;0;36.04017824401352;0;100;;true;true;1.3;-273.15
687;2300;0;;0;0;0;36.09758326888975;0;100;;true;true;1.3;-273.15
688;2300;0;;0;0;0;36.152387292168484;0;100;;true;true;1.3;-273.15
689;2300;0;;0;0;0;36.20448857866123;0;100;;true;true;1.3;-273.15
690;2300;0;;0;0;0;36.25412821113049;0;100;;true;true;1.3;-273.15
691;2300;0;;0;0;0;36.30160712406234;0;100;;true;true;1.3;-273.15
692;2300;0;;0;0;0;36.3471199798542;0;100;;true;true;1.3;-273.15
693;2300;0;;0;0;0;36.39075719201576;0;100;;true;true;1.3;-273.15
694;2300;0;;0;0;0;36.43254828912819;0;100;;true;true;1.3;-273.15
695;2300;0;;0;0;0;36.47251785968572;0;100;;true;true;1.3;-273.15
696;2300;0;;0;0;0;36.510873740152114;0;100;;true;true;1.3;-273.15
697;2300;0;;0;0;0;36.547534670177;0;100;;true;true;1.3;-273.15
698;2300;0;;0;0;0;36.582418853981274;0;100;;true;true;1.3;-273.15
699;2300;0;;0;0;0;36.61560785916747;0;100;;true;true;1.3;-273.15
700;2400;0;;0;0;0;36.64720695530803;0;100;;true;true;1.3;-273.15
701;2400;0;;0;0;0;36.858926521086886;0;100;;true;true;1.3;-273.15
702;2400;0;;0;0;0;37.14484309134601;0;100;;true;true;1.3;-273.15
703;2400;0;;0;0;0;37.36764407692352;0;100;;true;true;1.3;-273.15
704;2400;0;;0;0;0;37.48571057737091;0;100;;true;true;1.3;-273.15
705;2400;0;;0;0;0;37.53950869265186;0;100;;true;true;1.3;-273.15
706;2400;0;;0;0;0;37.58003549512052;0;100;;true;true;1.3;-273.15
707;2400;0;;0;0;0;37.6366711974982;0;100;;true;true;1.3;-273.15
708;2400;0;;0;0;0;37.71294588465109;0;100;;true;true;1.3;-273.15
709;2400;0;;0;0;0;37.79873062146066;0;100;;true;true;1.3;-273.15
710;2400;0;;0;0;0;37.882178023504636;0;100;;true;true;1.3;-273.15
711;2400;0;;0;0;0;37.95706622473609;0;100;;true;true;1.3;-273.15
712;2400;0;;0;0;0;38.02319985005076;0;100;;true;true;1.3;-273.15
713;2400;0;;0;0;0;38.083510355578085;0;100;;true;true;1.3;-273.15
714;2400;0;;0;0;0;38.14090913436024;0;100;;true;true;1.3;-273.15

Flow sweep with 1.55 sg (using Matlab)-simulation-sequence

715;2400;0;;0;0;0;38.19685447026758;0;100;;true>true;1.3;-273.15
716;2400;0;;0;0;0;38.25133637772017;0;100;;true>true;1.3;-273.15
717;2400;0;;0;0;0;38.303733412484355;0;100;;true>true;1.3;-273.15
718;2400;0;;0;0;0;38.353487463602434;0;100;;true>true;1.3;-273.15
719;2400;0;;0;0;0;38.40046690873694;0;100;;true>true;1.3;-273.15
720;2400;0;;0;0;0;38.444836857952275;0;100;;true>true;1.3;-273.15
721;2400;0;;0;0;0;38.4868852631957;0;100;;true>true;1.3;-273.15
722;2400;0;;0;0;0;38.52678415170698;0;100;;true>true;1.3;-273.15
723;2400;0;;0;0;0;38.56465635442306;0;100;;true>true;1.3;-273.15
724;2400;0;;0;0;0;38.600549075186684;0;100;;true>true;1.3;-273.15
725;2400;0;;0;0;0;38.63455854919317;0;100;;true>true;1.3;-273.15
726;2400;0;;0;0;0;38.66664020904358;0;100;;true>true;1.3;-273.15
727;2400;0;;0;0;0;38.696745779944294;0;100;;true>true;1.3;-273.15
728;2400;0;;0;0;0;38.72489943398486;0;100;;true>true;1.3;-273.15
729;2400;0;;0;0;0;38.75118660541261;0;100;;true>true;1.3;-273.15
730;2500;0;;0;0;0;38.77569957533657;0;100;;true>true;1.3;-273.15
731;2500;0;;0;0;0;38.9765868819641;0;100;;true>true;1.3;-273.15
732;2500;0;;0;0;0;39.24765587747366;0;100;;true>true;1.3;-273.15
733;2500;0;;0;0;0;39.4572916124625;0;100;;true>true;1.3;-273.15
734;2500;0;;0;0;0;39.56641606197043;0;100;;true>true;1.3;-273.15
735;2500;0;;0;0;0;39.61330751887228;0;100;;true>true;1.3;-273.15
736;2500;0;;0;0;0;39.64652092875559;0;100;;true>true;1.3;-273.15
737;2500;0;;0;0;0;39.69371762407552;0;100;;true>true;1.3;-273.15
738;2500;0;;0;0;0;39.75923989946314;0;100;;true>true;1.3;-273.15
739;2500;0;;0;0;0;39.83386582321617;0;100;;true>true;1.3;-273.15
740;2500;0;;0;0;0;39.90682185517683;0;100;;true>true;1.3;-273.15
741;2500;0;;0;0;0;39.97191696414208;0;100;;true>true;1.3;-273.15
742;2500;0;;0;0;0;40.02863213894021;0;100;;true>true;1.3;-273.15
743;2500;0;;0;0;0;40.07945285898889;0;100;;true>true;1.3;-273.15
744;2500;0;;0;0;0;40.127033873239114;0;100;;true>true;1.3;-273.15
745;2500;0;;0;0;0;40.17281458887967;0;100;;true>true;1.3;-273.15
746;2500;0;;0;0;0;40.216924110289106;0;100;;true>true;1.3;-273.15
747;2500;0;;0;0;0;40.25883330273023;0;100;;true>true;1.3;-273.15
748;2500;0;;0;0;0;40.29812606343095;0;100;;true>true;1.3;-273.15
749;2500;0;;0;0;0;40.33462907113357;0;100;;true>true;1.3;-273.15
750;2500;0;;0;0;0;40.368365844378154;0;100;;true>true;1.3;-273.15
751;2500;0;;0;0;0;40.399503802127576;0;100;;true>true;1.3;-273.15
752;2500;0;;0;0;0;40.42826025748462;0;100;;true>true;1.3;-273.15
753;2500;0;;0;0;0;40.45478412006711;0;100;;true>true;1.3;-273.15
754;2500;0;;0;0;0;40.479154302186046;0;100;;true>true;1.3;-273.15
755;2500;0;;0;0;0;40.501375789747236;0;100;;true>true;1.3;-273.15
756;2500;0;;0;0;0;40.521459613295065;0;100;;true>true;1.3;-273.15
757;2500;0;;0;0;0;40.53943473751698;0;100;;true>true;1.3;-273.15
758;2500;0;;0;0;0;40.55534701033398;0;100;;true>true;1.3;-273.15
759;2500;0;;0;0;0;40.569254100637494;0;100;;true>true;1.3;-273.15
760;2500;0;;0;0;0;40.58118506968068;0;100;;true>true;1.3;-273.15
761;2500;0;;0;0;0;40.5911871854406;0;100;;true>true;1.3;-273.15
762;2500;0;;0;0;0;40.599298754641985;0;100;;true>true;1.3;-273.15

Flow sweep with 1.55 sg (using Matlab)-simulation-sequence

763;2500;0;;0;0;0;40.6055639653144;0;100;;true>true;1.3;-273.15
764;2500;0;;0;0;0;40.60999821682446;0;100;;true>true;1.3;-273.15
765;2500;0;;0;0;0;40.6126327030111;0;100;;true>true;1.3;-273.15
766;2500;0;;0;0;0;40.6134960453801;0;100;;true>true;1.3;-273.15
767;2500;0;;0;0;0;40.61262367288564;0;100;;true>true;1.3;-273.15
768;2500;0;;0;0;0;40.61004696824772;0;100;;true>true;1.3;-273.15
769;2500;0;;0;0;0;40.605790174459955;0;100;;true>true;1.3;-273.15
770;2500;0;;0;0;0;40.59987707667851;0;100;;true>true;1.3;-273.15
771;2500;0;;0;0;0;40.592342091233945;0;100;;true>true;1.3;-273.15
772;2500;0;;0;0;0;40.583306864467836;0;100;;true>true;1.3;-273.15
773;2500;0;;0;0;0;40.57272589899025;0;100;;true>true;1.3;-273.15
774;2500;0;;0;0;0;40.56052197881927;0;100;;true>true;1.3;-273.15
775;2500;0;;0;0;0;40.54669815822701;0;100;;true>true;1.3;-273.15
776;2500;0;;0;0;0;40.53133285633583;0;100;;true>true;1.3;-273.15
777;2500;0;;0;0;0;40.51421284592593;0;100;;true>true;1.3;-273.15
778;2500;0;;0;0;0;40.49609675566306;0;100;;true>true;1.3;-273.15
779;2500;0;;0;0;0;40.476497740364685;0;100;;true>true;1.3;-273.15
780;2500;0;;0;0;0;40.45543104798026;0;100;;true>true;1.3;-273.15
781;2500;0;;0;0;0;40.43290044437392;0;100;;true>true;1.3;-273.15
782;2500;0;;0;0;0;40.40895233610462;0;100;;true>true;1.3;-273.15
783;2500;0;;0;0;0;40.3836564832368;0;100;;true>true;1.3;-273.15
784;2500;0;;0;0;0;40.357118836718584;0;100;;true>true;1.3;-273.15
785;2500;0;;0;0;0;40.32926930644029;0;100;;true>true;1.3;-273.15
786;2500;0;;0;0;0;40.30008376748359;0;100;;true>true;1.3;-273.15
787;2500;0;;0;0;0;40.269586753054696;0;100;;true>true;1.3;-273.15
788;2500;0;;0;0;0;40.237837525447276;0;100;;true>true;1.3;-273.15
789;2500;0;;0;0;0;40.204840837437054;0;100;;true>true;1.3;-273.15
790;2500;0;;0;0;0;40.17062319721331;0;100;;true>true;1.3;-273.15
791;2500;0;;0;0;0;40.13520253811604;0;100;;true>true;1.3;-273.15
792;2500;0;;0;0;0;40.09859534755067;0;100;;true>true;1.3;-273.15
793;2500;0;;0;0;0;40.06081293541687;0;100;;true>true;1.3;-273.15
794;2500;0;;0;0;0;40.02186987041737;0;100;;true>true;1.3;-273.15
795;2500;0;;0;0;0;39.981824138123756;0;100;;true>true;1.3;-273.15
796;2500;0;;0;0;0;39.940759022846365;0;100;;true>true;1.3;-273.15
797;2500;0;;0;0;0;39.89859740807416;0;100;;true>true;1.3;-273.15
798;2500;0;;0;0;0;39.85528254749578;0;100;;true>true;1.3;-273.15
799;2500;0;;0;0;0;39.810829278923926;0;100;;true>true;1.3;-273.15
800;2500;0;;0;0;0;39.76531346308458;0;100;;true>true;1.3;-273.15
801;2500;0;;0;0;0;39.71879789820175;0;100;;true>true;1.3;-273.15
802;2500;0;;0;0;0;39.67126493511774;0;100;;true>true;1.3;-273.15
803;2500;0;;0;0;0;39.62273856577709;0;100;;true>true;1.3;-273.15
804;2500;0;;0;0;0;39.573233522288696;0;100;;true>true;1.3;-273.15
805;2500;0;;0;0;0;39.52274270084761;0;100;;true>true;1.3;-273.15
806;2500;0;;0;0;0;39.47128900942698;0;100;;true>true;1.3;-273.15
807;2500;0;;0;0;0;39.418901071161585;0;100;;true>true;1.3;-273.15
808;2500;0;;0;0;0;39.36559681707454;0;100;;true>true;1.3;-273.15
809;2500;0;;0;0;0;39.311392150094484;0;100;;true>true;1.3;-273.15
810;2500;0;;0;0;0;39.25629642555951;0;100;;true>true;1.3;-273.15

Flow sweep with 1.55 sg (using Matlab)-simulation-sequence

811;2500;0;;0;0;0;39.20033000512681;0;100;;true>true;1.3;-273.15
812;2500;0;;0;0;0;39.14350565594852;0;100;;true>true;1.3;-273.15
813;2500;0;;0;0;0;39.08584631531655;0;100;;true>true;1.3;-273.15
814;2500;0;;0;0;0;39.02734988686055;0;100;;true>true;1.3;-273.15
815;2500;0;;0;0;0;38.96804264000833;0;100;;true>true;1.3;-273.15
816;2500;0;;0;0;0;38.9079346629604;0;100;;true>true;1.3;-273.15
817;2500;0;;0;0;0;38.8470424327332;0;100;;true>true;1.3;-273.15
818;2500;0;;0;0;0;38.785392530320564;0;100;;true>true;1.3;-273.15
819;2500;0;;0;0;0;38.723030276158106;0;100;;true>true;1.3;-273.15
820;2500;0;;0;0;0;38.660027867816375;0;100;;true>true;1.3;-273.15
821;2500;0;;0;0;0;38.59631995913577;0;100;;true>true;1.3;-273.15
822;2500;0;;0;0;0;38.53184287206642;0;100;;true>true;1.3;-273.15
823;2500;0;;0;0;0;38.4666002942847;0;100;;true>true;1.3;-273.15
824;2500;0;;0;0;0;38.40067121877194;0;100;;true>true;1.3;-273.15
825;2500;0;;0;0;0;38.33409647887674;0;100;;true>true;1.3;-273.15
826;2500;0;;0;0;0;38.26688679461223;0;100;;true>true;1.3;-273.15
827;2500;0;;0;0;0;38.19906689195488;0;100;;true>true;1.3;-273.15
828;2500;0;;0;0;0;38.13062934350701;0;100;;true>true;1.3;-273.15
829;2500;0;;0;0;0;38.061582761991104;0;100;;true>true;1.3;-273.15
830;2500;0;;0;0;0;37.99194435972859;0;100;;true>true;1.3;-273.15

Influx-simulation-sequence

Time (s);Main pump flow rate (l/min);Top of string speed (m/s);WOB auto driller ();WOB setpoint (ton);ROP setpoint (m/h);Surface RPM (rpm);Choke opening (%);Pump flow rate (l/min);BOP (%);Active pit ();Return pit ();Control active pit ();Active pit density (s.g.);Active pit temperature (°C)

1;2750;0;false;0;0;0;100;0;100;true;true;false;1.5;50
4;2750;0;false;0;0;0;100;0;100;true;true;true;1.568;20.050000000000001
147;2700;0;false;0;0;0;100;0;100;true;true;true;1.568;20.050000000000001
148;2650;0;false;0;0;0;100;0;100;true;true;true;1.568;20.050000000000001
149;2550;0;false;0;0;0;100;0;100;true;true;true;1.568;20.050000000000001
150;2450;0;false;0;0;0;100;0;100;true;true;true;1.568;20.050000000000001
154;2400;0;false;0;0;0;100;0;100;true;true;true;1.568;20.050000000000001
155;2350;0;false;0;0;0;100;0;100;true;true;true;1.568;20.050000000000001
164;2250;0;false;0;0;0;100;0;100;true;true;true;1.568;20.050000000000001
166;2150;0;false;0;0;0;100;0;100;true;true;true;1.568;20.050000000000001
214;2150;0;false;0;0;0;100;0;100;true;true;true;1.56;20.050000000000001
216;2150;0;false;0;0;0;100;0;100;true;true;true;1.55;20.050000000000001
217;2150;0;false;0;0;0;100;0;100;true;true;true;1.53;20.050000000000001
218;2150;0;false;0;0;0;100;0;100;true;true;true;1.5;20.050000000000001
224;2150;0;false;0;0;0;100;0;100;true;true;true;1.47;20.050000000000001
225;2150;0;false;0;0;0;100;0;100;true;true;true;1.46;20.050000000000001
232;2150;0;false;0;0;0;100;0;100;true;true;true;1.43;20.050000000000001
236;2150;0;false;0;0;0;100;0;100;true;true;true;1.42;20.050000000000001
242;2150;0;false;0;0;0;100;0;100;true;true;true;1.4;20.050000000000001
254;2150;0;false;0;0;0;100;0;100;true;true;true;1.37;20.050000000000001
261;2150;0;false;0;0;0;100;0;100;true;true;true;1.35;20.050000000000001
262;2150;0;false;0;0;0;100;0;100;true;true;true;1.34;20.050000000000001
269;2150;0;false;0;0;0;100;0;100;true;true;true;1.32;20.050000000000001
1494;2150;0;false;0;0;0;100;350;100;true;true;true;1.32;20.050000000000001
1495;2150;0;false;0;0;0;100;850;100;true;true;true;1.32;20.050000000000001
1496;2150;0;false;0;0;0;100;1300;100;true;true;true;1.32;20.050000000000001
1497;2150;0;false;0;0;0;100;1350;100;true;true;true;1.32;20.050000000000001
1524;2150;0;false;0;0;0;100;1400;100;true;true;true;1.32;20.050000000000001
1525;2150;0;false;0;0;0;100;1450;100;true;true;true;1.32;20.050000000000001
1526;2150;0;false;0;0;0;100;1500;100;true;true;true;1.32;20.050000000000001
1527;2150;0;false;0;0;0;100;1600;100;true;true;true;1.32;20.050000000000001
1532;2150;0;false;0;0;0;100;1650;100;true;true;true;1.32;20.050000000000001
1546;2150;0;false;0;0;0;96.93;1650;100;true;true;true;1.32;20.050000000000001
1547;2150;0;false;0;0;0;93.86;1650;100;true;true;true;1.32;20.050000000000001
1548;2150;0;false;0;0;0;93.25;1650;100;true;true;true;1.32;20.050000000000001
1549;2150;0;false;0;0;0;92.02;1650;100;true;true;true;1.32;20.050000000000001
1550;2150;0;false;0;0;0;90.79;1650;100;true;true;true;1.32;20.050000000000001
1551;2150;0;false;0;0;0;88.95;1650;100;true;true;true;1.32;20.050000000000001
1552;2150;0;false;0;0;0;87.11;1650;100;true;true;true;1.32;20.050000000000001
1553;2150;0;false;0;0;0;85.88;1650;100;true;true;true;1.32;20.050000000000001
1554;2150;0;false;0;0;0;84.65;1650;100;true;true;true;1.32;20.050000000000001
1555;2150;0;false;0;0;0;83.43;1650;100;true;true;true;1.32;20.050000000000001
1556;2150;0;false;0;0;0;81.58;1650;100;true;true;true;1.32;20.050000000000001
1557;2150;0;false;0;0;0;77.9;1650;100;true;true;true;1.32;20.050000000000001
1558;2150;0;false;0;0;0;77.29;1650;100;true;true;true;1.32;20.050000000000001

Influx-simulation-sequence

1559;2150;0;false;0;0;0;76.06;1650;100>true>true>true;1.32;20.050000000000001
1562;2150;0;false;0;0;0;75.44;1650;100>true>true>true;1.32;20.050000000000001
1563;2150;0;false;0;0;0;71.76;1650;100>true>true>true;1.32;20.050000000000001
1564;2150;0;false;0;0;0;68.69;1650;100>true>true>true;1.32;20.050000000000001
1565;2150;0;false;0;0;0;68.08;1650;100>true>true>true;1.32;20.050000000000001
1601;2150;0;false;0;0;0;68.08;1650;100>true>true>true;1.34;20.050000000000001
1602;2150;0;false;0;0;0;68.08;1650;100>true>true>true;1.38;20.050000000000001
1606;2150;0;false;0;0;0;68.08;1650;100>true>true>true;1.39;20.050000000000001
1607;2150;0;false;0;0;0;68.08;1650;100>true>true>true;1.41;20.050000000000001
1608;2150;0;false;0;0;0;68.08;1650;100>true>true>true;1.42;20.050000000000001
1620;2150;0;false;0;0;0;68.08;1650;100>true>true>true;1.43;20.050000000000001
1621;2150;0;false;0;0;0;68.08;1650;100>true>true>true;1.46;20.050000000000001
1624;2150;0;false;0;0;0;68.08;1650;100>true>true>true;1.47;20.050000000000001
1625;2150;0;false;0;0;0;68.08;1650;100>true>true>true;1.49;20.050000000000001
1626;2150;0;false;0;0;0;68.08;1650;100>true>true>true;1.5;20.050000000000001
1646;2150;0;false;0;0;0;66.85;1650;100>true>true>true;1.5;20.050000000000001
1647;2150;0;false;0;0;0;62.56;1650;100>true>true>true;1.5;20.050000000000001
1648;2150;0;false;0;0;0;55.8;1650;100>true>true>true;1.5;20.050000000000001
1649;2150;0;false;0;0;0;47.82;1650;100>true>true>true;1.5;20.050000000000001
1650;2150;0;false;0;0;0;41.07;1650;100>true>true>true;1.5;20.050000000000001
1651;2150;0;false;0;0;0;38;1650;100>true>true>true;1.5;20.050000000000001
1652;2150;0;false;0;0;0;34.93;1650;100>true>true>true;1.5;20.050000000000001
1653;2150;0;false;0;0;0;32.48;1650;100>true>true>true;1.5;20.050000000000001
1654;2150;0;false;0;0;0;31.25;1650;100>true>true>true;1.5;20.050000000000001
1691;2150;0;false;0;0;0;30.020000000000003;1650;100>true>true>true;1.5;20.050000000000001
1692;2150;0;false;0;0;0;29.410000000000004;1650;100>true>true>true;1.5;20.050000000000001
1695;2150;0;false;0;0;0;27.57;1650;100>true>true>true;1.5;20.050000000000001
1696;2150;0;false;0;0;0;26.340000000000003;1650;100>true>true>true;1.5;20.050000000000001
1706;2150;0;false;0;0;0;25.730000000000004;1650;100>true>true>true;1.5;20.050000000000001
1707;2150;0;false;0;0;0;22.04;1650;100>true>true>true;1.5;20.050000000000001
1732;2150;0;false;0;0;0;24.5;1650;100>true>true>true;1.5;20.050000000000001
1733;2150;0;false;0;0;0;26.950000000000003;1650;100>true>true>true;1.5;20.050000000000001
1754;2150;0;false;0;0;0;26.950000000000003;1750;100>true>true>true;1.5;20.050000000000001
1755;2150;0;false;0;0;0;26.950000000000003;1800;100>true>true>true;1.5;20.050000000000001
1756;2150;0;false;0;0;0;26.950000000000003;1850;100>true>true>true;1.5;20.050000000000001
1757;2150;0;false;0;0;0;26.950000000000003;1950;100>true>true>true;1.5;20.050000000000001
1817;2150;0;false;0;0;0;26.950000000000003;1950;100>true>true>true;1.51;20.050000000000001
1818;2150;0;false;0;0;0;26.950000000000003;1950;100>true>true>true;1.52;20.050000000000001
1820;2150;0;false;0;0;0;26.950000000000003;1950;100>true>true>true;1.53;20.050000000000001
1869;2200;0;false;0;0;0;26.950000000000003;1950;100>true>true>true;1.53;20.050000000000001
1906;2200;0;false;0;0;0;26.950000000000003;2000;100>true>true>true;1.53;20.050000000000001
1920;2200;0;false;0;0;0;25.72;2000;100>true>true>true;1.53;20.050000000000001
1921;2200;0;false;0;0;0;24.49;2000;100>true>true>true;1.53;20.050000000000001
2062;2200;0;false;0;0;0;23.88;2000;100>true>true>true;1.53;20.050000000000001
2063;2200;0;false;0;0;0;22.03;2000;100>true>true>true;1.53;20.050000000000001
2064;2200;0;false;0;0;0;20.81;2000;100>true>true>true;1.53;20.050000000000001
2065;2200;0;false;0;0;0;20.19;2000;100>true>true>true;1.53;20.050000000000001
2066;2200;0;false;0;0;0;19.58;2000;100>true>true>true;1.53;20.050000000000001

Influx-simulation-sequence

2164;2200;0;false;0;0;0;19.58;1850;100>true>true>true;1.53;20.05000000000001
2165;2200;0;false;0;0;0;19.58;1750;100>true>true>true;1.53;20.05000000000001
2622;2200;0;false;0;0;0;19.58;1850;100>true>true>true;1.53;20.05000000000001
2623;2200;0;false;0;0;0;19.58;1900.0000000000002;100>true>true>true;1.53;20.05000000000001
2626;2200;0;false;0;0;0;19.58;1950;100>true>true>true;1.53;20.05000000000001
2627;2200;0;false;0;0;0;19.58;2000;100>true>true>true;1.53;20.05000000000001
2712;2200;0;false;0;0;0;18.97;2000;100>true>true>true;1.53;20.05000000000001
2714;2200;0;false;0;0;0;17.74;2000;100>true>true>true;1.53;20.05000000000001
2715;2200;0;false;0;0;0;17.12;2000;100>true>true>true;1.53;20.05000000000001
2788;2200;0;false;0;0;0;17.12;2000;100>true>true>true;1.54;20.05000000000001
2789;2200;0;false;0;0;0;17.12;2000;100>true>true>true;1.55;20.05000000000001
2793;2200;0;false;0;0;0;17.12;2000;100>true>true>true;1.58;20.05000000000001
2794;2200;0;false;0;0;0;17.12;2000;100>true>true>true;1.59;20.05000000000001
3478;2200;0;false;0;0;0;19.58;2000;100>true>true>true;1.59;20.05000000000001
3479;2200;0;false;0;0;0;22.64;2000;100>true>true>true;1.59;20.05000000000001
3480;2200;0;false;0;0;0;23.87;2000;100>true>true>true;1.59;20.05000000000001
3483;2200;0;false;0;0;0;26.33;2000;100>true>true>true;1.59;20.05000000000001
3487;2200;0;false;0;0;0;26.94;2000;100>true>true>true;1.59;20.05000000000001
3527;2200;0;false;0;0;0;29.4;2000;100>true>true>true;1.59;20.05000000000001
3528;2200;0;false;0;0;0;32.46;2000;100>true>true>true;1.59;20.05000000000001
3529;2200;0;false;0;0;0;35.53;2000;100>true>true>true;1.59;20.05000000000001
3530;2200;0;false;0;0;0;37.38;2000;100>true>true>true;1.59;20.05000000000001
3531;2200;0;false;0;0;0;37.99;2000;100>true>true>true;1.59;20.05000000000001
3548;2200;0;false;0;0;0;37.38;2000;100>true>true>true;1.59;20.05000000000001
3549;2200;0;false;0;0;0;34.92;2000;100>true>true>true;1.59;20.05000000000001
3550;2200;0;false;0;0;0;32.46;2000;100>true>true>true;1.59;20.05000000000001
3551;2200;0;false;0;0;0;30.010000000000005;2000;100>true>true>true;1.59;20.05000000000001
3552;2200;0;false;0;0;0;27.55;2000;100>true>true>true;1.59;20.05000000000001
3553;2200;0;false;0;0;0;26.33;2000;100>true>true>true;1.59;20.05000000000001
3573;2200;0;false;0;0;0;25.1;2000;100>true>true>true;1.59;20.05000000000001
3574;2200;0;false;0;0;0;22.03;2000;100>true>true>true;1.59;20.05000000000001
3575;2200;0;false;0;0;0;20.19;2000;100>true>true>true;1.59;20.05000000000001
3577;2200;0;false;0;0;0;19.58;2000;100>true>true>true;1.59;20.05000000000001
3578;2200;0;false;0;0;0;18.96;2000;100>true>true>true;1.59;20.05000000000001
3579;2200;0;false;0;0;0;17.74;2000;100>true>true>true;1.59;20.05000000000001
4197;2200;0;false;0;0;0;17.74;2000;100>true>true>true;1.58;20.05000000000001
4198;2200;0;false;0;0;0;17.74;2000;100>true>true>true;1.57;20.05000000000001
4199;2200;0;false;0;0;0;17.74;2000;100>true>true>true;1.54;20.05000000000001
4200;2200;0;false;0;0;0;17.74;2000;100>true>true>true;1.53;20.05000000000001
4201;2200;0;false;0;0;0;17.74;2000;100>true>true>true;1.52;20.05000000000001
4202;2200;0;false;0;0;0;17.74;2000;100>true>true>true;1.51;20.05000000000001
4204;2200;0;false;0;0;0;17.74;2000;100>true>true>true;1.5;20.05000000000001
4209;2200;0;false;0;0;0;17.74;2000;100>true>true>true;1.53;20.05000000000001
4210;2200;0;false;0;0;0;17.74;2000;100>true>true>true;1.54;20.05000000000001
4216;2200;0;false;0;0;0;17.74;2000;100>true>true>true;1.55;20.05000000000001
4219;2200;0;false;0;0;0;17.74;2000;100>true>true>true;1.57;20.05000000000001
4223;2200;0;false;0;0;0;17.74;2000;100>true>true>true;1.56;20.05000000000001
4224;2200;0;false;0;0;0;17.74;2000;100>true>true>true;1.54;20.05000000000001

Influx-simulation-sequence

4230;2200;0;false;0;0;0;17.74;2000;100>true>true>true;1.53;20.05000000000001
4236;2200;0;false;0;0;0;17.74;2000;100>true>true>true;1.54;20.05000000000001
4240;2200;0;false;0;0;0;17.74;2000;100>true>true>true;1.55;20.05000000000001
4379;2200;0;false;0;0;0;18.35;2000;100>true>true>true;1.55;20.05000000000001
4380;2200;0;false;0;0;0;19.58;2000;100>true>true>true;1.55;20.05000000000001
4381;2200;0;false;0;0;0;20.2;2000;100>true>true>true;1.55;20.05000000000001
4382;2200;0;false;0;0;0;20.81;2000;100>true>true>true;1.55;20.05000000000001
4383;2200;0;false;0;0;0;22.65;2000;100>true>true>true;1.55;20.05000000000001
4392;2200;0;false;0;0;0;25.72;2000;100>true>true>true;1.55;20.05000000000001
4393;2200;0;false;0;0;0;26.33;2000;100>true>true>true;1.55;20.05000000000001
4469;2200;0;false;0;0;0;26.33;1850;100>true>true>true;1.55;20.05000000000001
4470;2200;0;false;0;0;0;26.33;1800;100>true>true>true;1.55;20.05000000000001
4471;2200;0;false;0;0;0;26.33;1600;100>true>true>true;1.55;20.05000000000001
4664;2200;0;false;0;0;0;28.17;1600;100>true>true>true;1.55;20.05000000000001
4665;2200;0;false;0;0;0;31.240000000000002;1600;100>true>true>true;1.55;20.05000000000001
4666;2200;0;false;0;0;0;33.7;1600;100>true>true>true;1.55;20.05000000000001
4736;2200;0;false;0;0;0;36.77;1600;100>true>true>true;1.55;20.05000000000001
4737;2200;0;false;0;0;0;38;1600;100>true>true>true;1.55;20.05000000000001
4810;2200;0;false;0;0;0;33.7;1600;100>true>true>true;1.55;20.05000000000001
4811;2200;0;false;0;0;0;32.48;1600;100>true>true>true;1.55;20.05000000000001
4872;2200;0;false;0;0;0;30.64;1600;100>true>true>true;1.55;20.05000000000001
4873;2200;0;false;0;0;0;30.020000000000003;1600;100>true>true>true;1.55;20.05000000000001
4935;2200;0;false;0;0;0;30.020000000000003;1550;100>true>true>true;1.55;20.05000000000001
4936;2200;0;false;0;0;0;30.020000000000003;1500;100>true>true>true;1.55;20.05000000000001
4937;2200;0;false;0;0;0;30.020000000000003;1450;100>true>true>true;1.55;20.05000000000001
4938;2200;0;false;0;0;0;30.020000000000003;1400;100>true>true>true;1.55;20.05000000000001
5143;2200;0;false;0;0;0;30.020000000000003;1350;100>true>true>true;1.55;20.05000000000001
5144;2200;0;false;0;0;0;30.020000000000003;1250;100>true>true>true;1.55;20.05000000000001
5145;2200;0;false;0;0;0;30.020000000000003;1200;100>true>true>true;1.55;20.05000000000001
5182;2200;0;false;0;0;0;30.020000000000003;1150;100>true>true>true;1.55;20.05000000000001
5183;2200;0;false;0;0;0;30.020000000000003;1100;100>true>true>true;1.55;20.05000000000001
5184;2200;0;false;0;0;0;30.020000000000003;1050;100>true>true>true;1.55;20.05000000000001
5186;2200;0;false;0;0;0;30.020000000000003;1000;100>true>true>true;1.55;20.05000000000001
5404;2200;0;false;0;0;0;30.630000000000003;1000;100>true>true>true;1.55;20.05000000000001
5405;2200;0;false;0;0;0;31.86;1000;100>true>true>true;1.55;20.05000000000001
5407;2200;0;false;0;0;0;33.09;1000;100>true>true>true;1.55;20.05000000000001
5408;2200;0;false;0;0;0;33.7;1000;100>true>true>true;1.55;20.05000000000001
5409;2200;0;false;0;0;0;34.32;1000;100>true>true>true;1.55;20.05000000000001
5421;2200;0;false;0;0;0;36.16;1000;100>true>true>true;1.55;20.05000000000001
5422;2200;0;false;0;0;0;38.61;1000;100>true>true>true;1.55;20.05000000000001
5924;2200;0;false;0;0;0;38.61;1000;100>true>true>true;1.55;20.05000000000001

Losing and influx-simulation-sequence

Time (s);Main pump flow rate (l/min);Top of string speed (m/s);WOB auto driller ();WOB setpoint (ton);ROP setpoint (m/h);Surface RPM (rpm);Choke opening (%);Pump flow rate (l/min);BOP (%);Active pit ();Return pit ();Control active pit ();Active pit density (s.g.);Active pit temperature (°C)

1;2450;0;false;0;0;0;100;0;100>true>true>false;1.5;50
227;2450;0;false;0;0;0;100;0;100>true>true>true;1.569;18.450000000000045
271;2450;0;false;0;0;0;92.02;0;100>true>true>true;1.569;18.450000000000045
272;2450;0;false;0;0;0;66.26;0;100>true>true>true;1.569;18.450000000000045
273;2450;0;false;0;0;0;39.88;0;100>true>true>true;1.569;18.450000000000045
274;2450;0;false;0;0;0;36.2;0;100>true>true>true;1.569;18.450000000000045
275;2450;0;false;0;0;0;32.52;0;100>true>true>true;1.569;18.450000000000045
329;2450;0;false;0;0;0;31.290000000000003;0;100>true>true>true;1.569;18.450000000000045
330;2450;0;false;0;0;0;27;0;100>true>true>true;1.569;18.450000000000045
331;2450;0;false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
375;2200;0;false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
376;1900.0000000000002;0;false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
377;1700;0;false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
378;1450;0;false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
379;1150;0;false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
380;800;0;false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
381;600;0;false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
382;250;0;false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
383;0;0;false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
407;0;0;false;0;0;0;25.77;50;100>true>true>true;1.569;18.450000000000045
408;0;0;false;0;0;0;25.77;100;100>true>true>true;1.569;18.450000000000045
411;0;0;false;0;0;0;25.77;350;100>true>true>true;1.569;18.450000000000045
412;0;0;false;0;0;0;25.77;750;100>true>true>true;1.569;18.450000000000045
413;0;0;false;0;0;0;25.77;850;100>true>true>true;1.569;18.450000000000045
414;0;0;false;0;0;0;25.77;950.0000000000001;100>true>true>true;1.569;18.450000000000045
415;0;0;false;0;0;0;25.77;1000;100>true>true>true;1.569;18.450000000000045
417;0;0;false;0;0;0;25.77;1100;100>true>true>true;1.569;18.450000000000045
418;0;0;false;0;0;0;25.77;1200;100>true>true>true;1.569;18.450000000000045
419;0;0;false;0;0;0;25.77;1300;100>true>true>true;1.569;18.450000000000045
420;0;0;false;0;0;0;25.77;1350;100>true>true>true;1.569;18.450000000000045
421;0;0;false;0;0;0;25.77;1600;100>true>true>true;1.569;18.450000000000045
423;0;0;false;0;0;0;25.77;1650;100>true>true>true;1.569;18.450000000000045
425;0;0;false;0;0;0;25.77;1800;100>true>true>true;1.569;18.450000000000045
426;0;0;false;0;0;0;25.77;1850;100>true>true>true;1.569;18.450000000000045
439;0;0;false;0;0;0;25.77;1900.0000000000002;100>true>true>true;1.569;18.450000000000045
441;0;0;false;0;0;0;25.77;1950;100>true>true>true;1.569;18.450000000000045
568;1350;0;false;0;0;0;25.77;1950;100>true>true>true;1.569;18.450000000000045
569;2990;0;false;0;0;0;25.77;1950;100>true>true>true;1.569;18.450000000000045
581;2990;0;false;0;0;0;25.77;450;100>true>true>true;1.569;18.450000000000045
582;2990;0;false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
861;2950;0;false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
862;2800;0;false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
863;2550;0;false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
864;2350;0;false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
865;2050;0;false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045

Losing and influx-simulation-sequence

866;1900.0000000000002;0>false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
867;1800;0>false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
868;1500;0>false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
869;1350;0>false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
870;1250;0>false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
871;1000;0>false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
872;800;0>false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
873;400;0>false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
874;150;0>false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
876;0;0>false;0;0;0;25.77;0;100>true>true>true;1.569;18.450000000000045
886;0;0>false;0;0;0;25.77;150;100>true>true>true;1.569;18.450000000000045
887;0;0>false;0;0;0;25.77;500;100>true>true>true;1.569;18.450000000000045
888;0;0>false;0;0;0;25.77;700;100>true>true>true;1.569;18.450000000000045
889;0;0>false;0;0;0;25.77;950.0000000000001;100>true>true>true;1.569;18.450000000000045
890;0;0>false;0;0;0;25.77;1000;100>true>true>true;1.569;18.450000000000045
892;0;0>false;0;0;0;25.77;1100;100>true>true>true;1.569;18.450000000000045
893;0;0>false;0;0;0;25.77;1200;100>true>true>true;1.569;18.450000000000045
894;0;0>false;0;0;0;25.77;1250;100>true>true>true;1.569;18.450000000000045
896;0;0>false;0;0;0;25.77;1300;100>true>true>true;1.569;18.450000000000045
901;0;0>false;0;0;0;25.77;1500;100>true>true>true;1.569;18.450000000000045
902;0;0>false;0;0;0;25.77;1550;100>true>true>true;1.569;18.450000000000045
904;0;0>false;0;0;0;25.77;1600;100>true>true>true;1.569;18.450000000000045
925;0;0>false;0;0;0;25.77;1700;100>true>true>true;1.569;18.450000000000045
926;0;0>false;0;0;0;25.77;1850;100>true>true>true;1.569;18.450000000000045
927;0;0>false;0;0;0;25.77;1900.0000000000002;100>true>true>true;1.569;18.450000000000045
928;0;0>false;0;0;0;25.77;1950;100>true>true>true;1.569;18.450000000000045
943;0;0>false;0;0;0;25.77;2000;100>true>true>true;1.569;18.450000000000045
990;0;0>false;0;0;0;25.77;2000;100>true>true>true;1.7;18.450000000000045
1767;0;0>false;0;0;0;23.93;2000;100>true>true>true;1.7;18.450000000000045
1768;0;0>false;0;0;0;22.09;2000;100>true>true>true;1.7;18.450000000000045
1769;0;0>false;0;0;0;21.48;2000;100>true>true>true;1.7;18.450000000000045
1772;0;0>false;0;0;0;20.86;2000;100>true>true>true;1.7;18.450000000000045
1773;0;0>false;0;0;0;20.25;2000;100>true>true>true;1.7;18.450000000000045
1794;0;0>false;0;0;0;19.02;2000;100>true>true>true;1.7;18.450000000000045
1795;0;0>false;0;0;0;17.8;2000;100>true>true>true;1.7;18.450000000000045
5313;0;0>false;0;0;0;17.8;1350;100>true>true>true;1.7;18.450000000000045
5314;0;0>false;0;0;0;17.8;0;100>true>true>true;1.7;18.450000000000045
5328;1650;0>false;0;0;0;17.8;0;100>true>true>true;1.7;18.450000000000045
5329;2150;0>false;0;0;0;17.8;0;100>true>true>true;1.7;18.450000000000045
5330;2600;0>false;0;0;0;17.8;0;100>true>true>true;1.7;18.450000000000045
5333;2500;0>false;0;0;0;17.8;0;100>true>true>true;1.7;18.450000000000045
5334;2450;0>false;0;0;0;17.8;0;100>true>true>true;1.7;18.450000000000045
5336;2400;0>false;0;0;0;17.8;0;100>true>true>true;1.7;18.450000000000045
5339;2350;0>false;0;0;0;17.8;0;100>true>true>true;1.7;18.450000000000045
5342;2250;0>false;0;0;0;17.8;0;100>true>true>true;1.7;18.450000000000045
5343;2200;0>false;0;0;0;17.8;0;100>true>true>true;1.7;18.450000000000045
5344;2150;0>false;0;0;0;17.8;0;100>true>true>true;1.7;18.450000000000045
5345;2100;0>false;0;0;0;17.8;0;100>true>true>true;1.7;18.450000000000045

Losing and influx-simulation-sequence

5348;1850;0;false;0;0;0;17.8;0;100;true;true;true;1.7;18.450000000000045
5349;1800;0;false;0;0;0;17.8;0;100;true;true;true;1.7;18.450000000000045
5374;1450;0;false;0;0;0;17.8;0;100;true;true;true;1.7;18.450000000000045
5412;1200;0;false;0;0;0;17.8;0;100;true;true;true;1.7;18.450000000000045
5427;1150;0;false;0;0;0;17.8;0;100;true;true;true;1.7;18.450000000000045
5428;1050;0;false;0;0;0;17.8;0;100;true;true;true;1.7;18.450000000000045
5430;900;0;false;0;0;0;17.8;0;100;true;true;true;1.7;18.450000000000045
5434;1000;0;false;0;0;0;17.8;0;100;true;true;true;1.7;18.450000000000045
5435;1700;0;false;0;0;0;17.8;0;100;true;true;true;1.7;18.450000000000045
5444;1750;0;false;0;0;0;17.8;0;100;true;true;true;1.7;18.450000000000045
5445;1800;0;false;0;0;0;17.8;0;100;true;true;true;1.7;18.450000000000045
5465;1850;0;false;0;0;0;17.8;0;100;true;true;true;1.7;18.450000000000045
5481;1900.0000000000002;0;false;0;0;0;17.8;0;100;true;true;true;1.7;18.450000000000045
5492;1950;0;false;0;0;0;17.8;0;100;true;true;true;1.7;18.450000000000045
5510;2000;0;false;0;0;0;17.8;0;100;true;true;true;1.7;18.450000000000045
8238;2000;0;false;0;0;0;19.03;0;100;true;true;true;1.7;18.450000000000045
8239;2000;0;false;0;0;0;20.25;0;100;true;true;true;1.7;18.450000000000045
8241;2000;0;false;0;0;0;20.87;0;100;true;true;true;1.7;18.450000000000045
8242;2000;0;false;0;0;0;21.48;0;100;true;true;true;1.7;18.450000000000045
8264;2000;0;false;0;0;0;22.09;0;100;true;true;true;1.7;18.450000000000045
8268;2000;0;false;0;0;0;22.71;0;100;true;true;true;1.7;18.450000000000045
8278;2000;0;false;0;0;0;23.93;0;100;true;true;true;1.7;18.450000000000045
8281;2000;0;false;0;0;0;24.55;0;100;true;true;true;1.7;18.450000000000045
8283;2000;0;false;0;0;0;25.16;0;100;true;true;true;1.7;18.450000000000045
8284;2000;0;false;0;0;0;27;0;100;true;true;true;1.7;18.450000000000045
8285;2000;0;false;0;0;0;27.62;0;100;true;true;true;1.7;18.450000000000045
8286;2000;0;false;0;0;0;28.84;0;100;true;true;true;1.7;18.450000000000045
8300;2000;0;false;0;0;0;33.14;0;100;true;true;true;1.7;18.450000000000045
8301;2000;0;false;0;0;0;34.36;0;100;true;true;true;1.7;18.450000000000045
8302;2000;0;false;0;0;0;35.59;0;100;true;true;true;1.7;18.450000000000045
8313;2000;0;false;0;0;0;36.2;0;100;true;true;true;1.7;18.450000000000045
8316;2000;0;false;0;0;0;36.82;0;100;true;true;true;1.7;18.450000000000045
8317;2000;0;false;0;0;0;38.05;0;100;true;true;true;1.7;18.450000000000045
8321;2000;0;false;0;0;0;38.66;0;100;true;true;true;1.7;18.450000000000045
8324;2000;0;false;0;0;0;41.73;0;100;true;true;true;1.7;18.450000000000045
8325;2000;0;false;0;0;0;45.41;0;100;true;true;true;1.7;18.450000000000045
8352;2000;0;false;0;0;0;49.09;0;100;true;true;true;1.7;18.450000000000045
8353;2000;0;false;0;0;0;50.93;0;100;true;true;true;1.7;18.450000000000045
8430;2000;0;false;0;0;0;51.54;0;100;true;true;true;1.7;18.450000000000045
8431;2000;0;false;0;0;0;58.91;0;100;true;true;true;1.7;18.450000000000045
8433;2000;0;false;0;0;0;60.13;0;100;true;true;true;1.7;18.450000000000045
8434;2000;0;false;0;0;0;60.75000000000001;0;100;true;true;true;1.7;18.450000000000045
8439;2000;0;false;0;0;0;65.04;0;100;true;true;true;1.7;18.450000000000045
8464;2000;0;false;0;0;0;67.49;0;100;true;true;true;1.7;18.450000000000045
8465;2000;0;false;0;0;0;74.24;0;100;true;true;true;1.7;18.450000000000045
8466;2000;0;false;0;0;0;76.08;0;100;true;true;true;1.7;18.450000000000045
8518;2000;0;false;0;0;0;76.08;0;100;true;true;true;1.67;18.450000000000045
8519;2000;0;false;0;0;0;76.08;0;100;true;true;true;1.58;18.450000000000045

Losing and influx-simulation-sequence

8524;2000;0;false;0;0;0;76.08;0;100>true>true>true;1.56;18.450000000000045
12538;2050;0;false;0;0;0;76.08;0;100>true>true>true;1.56;18.450000000000045
12539;2100;0;false;0;0;0;76.08;0;100>true>true>true;1.56;18.450000000000045
12540;2200;0;false;0;0;0;76.08;0;100>true>true>true;1.56;18.450000000000045
13081;2250;0;false;0;0;0;76.08;0;100>true>true>true;1.56;18.450000000000045
13082;2400;0;false;0;0;0;76.08;0;100>true>true>true;1.56;18.450000000000045
13083;2450;0;false;0;0;0;76.08;0;100>true>true>true;1.56;18.450000000000045
13084;2500;0;false;0;0;0;76.08;0;100>true>true>true;1.56;18.450000000000045
13126;2500;0;false;0;0;0;74.24;0;100>true>true>true;1.56;18.450000000000045
13127;2500;0;false;0;0;0;73.01;0;100>true>true>true;1.56;18.450000000000045
13128;2500;0;false;0;0;0;71.79;0;100>true>true>true;1.56;18.450000000000045
13131;2500;0;false;0;0;0;71.17;0;100>true>true>true;1.56;18.450000000000045
13132;2500;0;false;0;0;0;68.1;0;100>true>true>true;1.56;18.450000000000045
13133;2500;0;false;0;0;0;67.49;0;100>true>true>true;1.56;18.450000000000045
13149;2500;0;false;0;0;0;66.26;0;100>true>true>true;1.56;18.450000000000045
13150;2500;0;false;0;0;0;63.81;0;100>true>true>true;1.56;18.450000000000045
13151;2500;0;false;0;0;0;61.970000000000006;0;100>true>true>true;1.56;18.450000000000045
13152;2500;0;false;0;0;0;61.360000000000001;0;100>true>true>true;1.56;18.450000000000045
13164;2500;0;false;0;0;0;60.13;0;100>true>true>true;1.56;18.450000000000045
13165;2500;0;false;0;0;0;54;0;100>true>true>true;1.56;18.450000000000045
13166;2500;0;false;0;0;0;50.93;0;100>true>true>true;1.56;18.450000000000045
13167;2500;0;false;0;0;0;47.86;0;100>true>true>true;1.56;18.450000000000045
13170;2500;0;false;0;0;0;46.64;0;100>true>true>true;1.56;18.450000000000045
13171;2500;0;false;0;0;0;28.84;0;100>true>true>true;1.56;18.450000000000045
14410;2500;0;false;0;0;0;28.84;0;100>true>true>true;1.56;18.450000000000045

Mud loss without controlling -simulation-sequence

Time (s);Main pump flow rate (l/min);Top of string speed (m/s);WOB auto driller ();WOB setpoint (ton);ROP setpoint (m/h);Surface RPM (rpm);Choke opening (%);Pump flow rate (l/min);BOP (%);Active pit ();Return pit ();Control active pit ();Active pit density (s.g.);Active pit temperature (°C)

1;2350;0;false;0;0;0;100;0;100>true>true>true;1.55;20
375;2350;0;false;0;0;0;95.09;0;100>true>true>true;1.55;20
376;2350;0;false;0;0;0;81.6;0;100>true>true>true;1.55;20
377;2350;0;false;0;0;0;65.64;0;100>true>true>true;1.55;20
378;2350;0;false;0;0;0;60.12;0;100>true>true>true;1.55;20
379;2350;0;false;0;0;0;56.44;0;100>true>true>true;1.55;20
380;2350;0;false;0;0;0;51.53;0;100>true>true>true;1.55;20
381;2350;0;false;0;0;0;43.56;0;100>true>true>true;1.55;20
382;2350;0;false;0;0;0;41.1;0;100>true>true>true;1.55;20
383;2350;0;false;0;0;0;36.2;0;100>true>true>true;1.55;20
428;2350;0;false;0;0;0;34.36;0;100>true>true>true;1.55;20
429;2350;0;false;0;0;0;31.290000000000003;0;100>true>true>true;1.55;20
430;2350;0;false;0;0;0;30.070000000000004;0;100>true>true>true;1.55;20
936;2350;0;false;0;0;0;26.39;0;100>true>true>true;1.55;20
937;2350;0;false;0;0;0;19.64;0;100>true>true>true;1.55;20
938;2350;0;false;0;0;0;16.57;0;100>true>true>true;1.55;20
939;2350;0;false;0;0;0;14.730000000000002;0;100>true>true>true;1.55;20
945;2350;0;false;0;0;0;15.960000000000003;0;100>true>true>true;1.55;20
946;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;20
968;2350;0;false;0;0;0;17.8;0;100>true>true>true;1.55;20
969;2350;0;false;0;0;0;19.64;0;100>true>true>true;1.55;20
976;2350;0;false;0;0;0;20.25;0;100>true>true>true;1.55;20
990;2350;0;false;0;0;0;19.03;0;100>true>true>true;1.55;20
1020;2350;0;false;0;0;0;17.8;0;100>true>true>true;1.55;20
1021;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;20
1041;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;43
1042;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;45
1045;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;48
1202;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;54
1203;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;57
1204;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;61
1205;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;64
1206;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;69
1207;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;71
1211;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;76
4631;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;83
4633;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;85
4634;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;86
4635;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;88
4636;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;89
4650;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;91
4659;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;90
14410;2350;0;false;0;0;0;17.19;0;100>true>true>true;1.55;90

No influx-simulation-sequence

Time (s);Main pump flow rate (l/min);Top of string speed (m/s);WOB auto driller
();WOB setpoint (ton);ROP setpoint (m/h);Surface RPM (rpm);Choke opening
(%);Pump flow rate (l/min);BOP (%);Active pit ();Return pit ();Control active pit
();Active pit density (s.g.);Active pit temperature (°C)

1;2550;0.196>false;0;100;111;100;0;100>true>true>true;1.55;20
334;2550;0.196>false;0;100;111;100;0;100>true>true>true;1.57;20
337;2550;0.196>false;0;100;111;100;0;100>true>true>true;1.58;20
452;2450;0.196>false;0;100;111;100;0;100>true>true>true;1.58;20
454;2350;0.196>false;0;100;111;100;0;100>true>true>true;1.58;20
458;2250;0.196>false;0;100;111;100;0;100>true>true>true;1.58;20
572;2250;0.196>false;0;100;111;100;0;100>true>true>true;1.6;20
574;2250;0.196>false;0;100;111;100;0;100>true>true>true;1.61;20
1427;2250;0.196>false;0;100;111;87.73;0;100>true>true>true;1.61;20
1428;2250;0.196>false;0;100;111;58.28;0;100>true>true>true;1.61;20
1444;2250;0.196>false;0;100;111;54.6;0;100>true>true>true;1.61;20
1445;2250;0.196>false;0;100;111;46.63;0;100>true>true>true;1.61;20
1492;2250;0.196>false;0;100;111;42.95;0;100>true>true>true;1.61;20
1493;2250;0.196>false;0;100;111;31.91;0;100>true>true>true;1.61;20
1557;2250;0.196>false;0;100;111;31.91;0;100>true>true>true;1.55;20
1558;2250;0.196>false;0;100;111;31.91;0;100>true>true>true;1.51;20
1567;2250;0.196>false;0;100;111;31.91;0;100>true>true>true;1.52;20
1577;2250;0.196>false;0;100;111;31.91;0;100>true>true>true;1.53;20
1579;2250;0.196>false;0;100;111;31.91;0;100>true>true>true;1.54;20
1596;2250;0.196>false;0;100;111;31.91;0;100>true>true>true;1.55;20
1604;2250;0.196>false;0;100;111;31.91;0;100>true>true>true;1.52;20
1605;2250;0.196>false;0;100;111;31.91;0;100>true>true>true;1.44;20
1606;2250;0.196>false;0;100;111;31.91;0;100>true>true>true;1.43;20
1846;2300;0.196>false;0;100;111;31.91;0;100>true>true>true;1.43;20
1847;2350;0.196>false;0;100;111;31.91;0;100>true>true>true;1.43;20
1851;2700;0.196>false;0;100;111;31.91;0;100>true>true>true;1.43;20
1852;2800;0.196>false;0;100;111;31.91;0;100>true>true>true;1.43;20
1855;2450;0.196>false;0;100;111;31.91;0;100>true>true>true;1.43;20
1856;2350;0.196>false;0;100;111;31.91;0;100>true>true>true;1.43;20
1893;2400;0.196>false;0;100;111;31.91;0;100>true>true>true;1.43;20
1919;2400;0.196>false;0;100;111;31.3;0;100>true>true>true;1.43;20
1927;2400;0.196>false;0;100;111;31.91;0;100>true>true>true;1.43;20
1929;2400;0.196>false;0;100;111;33.75;0;100>true>true>true;1.43;20
1962;2400;0.196>false;0;100;111;33.14;0;100>true>true>true;1.43;20
1963;2400;0.196>false;0;100;111;31.3;0;100>true>true>true;1.43;20
1964;2400;0.196>false;0;100;111;20.87;0;100>true>true>true;1.43;20
1970;2400;0.196>false;0;100;111;23.94;0;100>true>true>true;1.43;20
1971;2400;0.196>false;0;100;111;31.3;0;100>true>true>true;1.43;20
2085;2400;0.196>false;0;100;111;32.53;0;100>true>true>true;1.43;20
2086;2400;0.196>false;0;100;111;34.98;0;100>true>true>true;1.43;20
2162;2400;0.196>false;0;100;111;38.66;0;100>true>true>true;1.43;20
2163;2400;0.196>false;0;100;111;39.89;0;100>true>true>true;1.43;20
2445;2400;0.196>false;0;100;111;41.12;0;100>true>true>true;1.43;20
2447;2400;0.196>false;0;100;111;43.57;0;100>true>true>true;1.43;20
2448;2400;0.196>false;0;100;111;45.41;0;100>true>true>true;1.43;20

No influx-simulation-sequence

2449;2400;0.196>false;0;100;111;47.87;0;100>true>true>true;1.43;20
2450;2400;0.196>false;0;100;111;51.55;0;100>true>true>true;1.43;20
2451;2400;0.196>false;0;100;111;52.16;0;100>true>true>true;1.43;20
2452;2400;0.196>false;0;100;111;54;0;100>true>true>true;1.43;20
2471;2500;0.196>false;0;100;111;54;0;100>true>true>true;1.43;20
2473;2550;0.196>false;0;100;111;54;0;100>true>true>true;1.43;20
3061;2550;0.196>false;0;100;111;52.16;0;100>true>true>true;1.43;20
3062;2550;0.196>false;0;100;111;49.71;0;100>true>true>true;1.43;20
3067;2550;0.196>false;0;100;111;46.64;0;100>true>true>true;1.43;20
3130;2600;0.196>false;0;100;111;46.64;0;100>true>true>true;1.43;20
3132;2500;0.196>false;0;100;111;46.64;0;100>true>true>true;1.43;20
3143;2450;0.196>false;0;100;111;46.64;0;100>true>true>true;1.43;20
3144;2400;0.196>false;0;100;111;46.64;0;100>true>true>true;1.43;20
3145;2350;0.196>false;0;100;111;46.64;0;100>true>true>true;1.43;20
3194;2350;0.196>false;0;100;111;46.64;0;100>true>true>true;1.44;20
3195;2350;0.196>false;0;100;111;46.64;0;100>true>true>true;1.48;20
3201;2350;0.196>false;0;100;111;46.64;0;100>true>true>true;1.5;20
3202;2350;0.196>false;0;100;111;46.64;0;100>true>true>true;1.51;20
3210;2350;0.196>false;0;100;111;46.64;0;100>true>true>true;1.52;20
3216;2350;0.196>false;0;100;111;46.64;0;100>true>true>true;1.53;20
3227;2350;0.196>false;0;100;111;46.64;0;100>true>true>true;1.54;20
3239;2350;0.196>false;0;100;111;46.64;0;100>true>true>true;1.55;20
3352;2350;0.196>false;0;100;111;44.8;0;100>true>true>true;1.55;20
3353;2350;0.196>false;0;100;111;38.66;0;100>true>true>true;1.55;20
3354;2350;0.196>false;0;100;111;37.44;0;100>true>true>true;1.55;20
3374;2350;0.196>false;0;100;111;36.83;0;100>true>true>true;1.55;20
3375;2350;0.196>false;0;100;111;34.37;0;100>true>true>true;1.55;20
3377;2350;0.196>false;0;100;111;31.920000000000005;0;100>true>true>true;1.55;20
3467;2350;0.196>false;0;100;111;29.469999999999995;0;100>true>true>true;1.55;20
3468;2350;0.196>false;0;100;111;26.400000000000002;0;100>true>true>true;1.55;20
3475;2350;0.196>false;0;100;111;25.790000000000003;0;100>true>true>true;1.55;20
3476;2350;0.196>false;0;100;111;25.17;0;100>true>true>true;1.55;20
3629;2350;0.196>false;0;100;111;23.94;0;100>true>true>true;1.55;20
3630;2350;0.196>false;0;100;111;22.1;0;100>true>true>true;1.55;20
3631;2350;0.196>false;0;100;111;21.49;0;100>true>true>true;1.55;20
3638;2350;0.196>false;0;100;111;23.33;0;100>true>true>true;1.55;20
3884;2400;0.196>false;0;100;111;23.33;0;100>true>true>true;1.55;20
3890;2450;0.196>false;0;100;111;23.33;0;100>true>true>true;1.55;20
4010;2450;0.196>false;0;100;111;23.33;0;100>true>true>true;1.56;20
4015;2450;0.196>false;0;100;111;23.33;0;100>true>true>true;1.57;20
4025;2450;0.196>false;0;100;111;23.33;0;100>true>true>true;1.59;20
4164;2450;0.196>false;0;100;111;25.17;0;100>true>true>true;1.59;20
4165;2450;0.196>false;0;100;111;37.44;0;100>true>true>true;1.59;20
4166;2450;0.196>false;0;100;111;39.89;0;100>true>true>true;1.59;20
4191;2450;0.196>false;0;100;111;29.460000000000004;0;100>true>true>true;1.59;20
4192;2450;0.196>false;0;100;111;25.78;0;100>true>true>true;1.59;20
4198;2450;0.196>false;0;100;111;23.33;0;100>true>true>true;1.59;20
4203;2450;0.196>false;0;100;111;22.71;0;100>true>true>true;1.59;20

No influx-simulation-sequence

4209;2450;0.196;false;0;100;111;21.49;0;100>true>true>true;1.59;20
4234;2450;0.196;false;0;100;111;17.8;0;100>true>true>true;1.59;20
4243;2450;0.196;false;0;100;111;17.19;0;100>true>true>true;1.59;20
4273;2450;0.196;false;0;100;111;17.8;0;100>true>true>true;1.59;20
4274;2450;0.196;false;0;100;111;18.42;0;100>true>true>true;1.59;20
4297;2450;0.196;false;0;100;111;19.03;0;100>true>true>true;1.59;20
4298;2450;0.196;false;0;100;111;19.65;0;100>true>true>true;1.59;20
4301;2450;0.196;false;0;100;111;20.26;0;100>true>true>true;1.59;20
4882;2450;0.196;false;0;100;111;20.26;0;100>true>true>true;1.59;20

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