Universitetet
i Stavanger

Faculty of Science and Technology

MASTER`S THESIS

Study program / Specialization: Master of Science in Industrial Economy, contract administration	Spring semester, 2012. Open
Writer: Bernt-Andrè Lorentsen	………………………………………… (Writer`s signature)
Faculty supervisor: Steinar Evje External supervisor: Dag Ove Molde, Statoil ASA	
Title of thesis: **Evaluation of a full scale drilling simulator**	
Credits (ECTS): 30	
Key words: Conventional Drilling Managed Pressure Drilling Drilling Simulator Simulator training	Pages: ………………… + enclosure: ………… Stavanger, ………………..

Abstract

Nowadays, one can often hear the saying: “the easy oil is gone, the future will bring more complex and challenging wells to be drilled”. In fact, this is something the industry already is facing. Oilfields are depleting and ageing, which forces the operators to search for oil and gas in harsher and more challenging areas. This thesis presents a detailed description of a full scale drilling simulator developed by Statoil and cooperating partners; SINTEF, eDrilling and Oiltec Solutions. The simulator was developed as a consequence of several serious incidents during the period 2007 – 2008. Statoil`s intention is to ensure optimal competence level for its Drilling & Well personnel by offering realistic personnel training on operational procedures and well control incidents in a non-threatening environment. This gives each license a unique opportunity to train of field specific challenges.

The simulator contains a great flexibility due to its modularity which enables training on a variety of different drilling operations. As of today, is conventional drilling fully implemented with capability of performing training in HPHT mode. Generally will MPD operations require more equipment and a higher competence requirement compared to conventional drilling, and will thus require more time for training. The newly developed MPD module will be implemented during the month of July. Since this is the next extension of drilling simulator application, have this thesis assessed the potential of performing training of drilling & well personnel in MPD mode. Related drilling problems have also been presented due to its relevance for simulator training in both conventional drilling and MPD mode.

Successful training and improvement of personnel`s action in different scenarios requires realistic cases with a rig setup close to what the personnel is used to. Hence, the simulator is configured to replicate the actual drilling rig and well data for applicable wells. A comparison between Statoil`s in-house planning tool, Drillbench, and SINTEF`s, Intellectus, have been presented in a comparison of simulated results. The result shows that both planning tools are to be consistent and aligned and shows that simulated data from simulator training is in accordance with the planning each licensee have performed in advance. An comparison of real-time ECD and simulated ECD values shows that Drillbench conducts simulations that are both reliable and realistic when the drilling parameters are the same.

Through the period from January 2012 – June 2012, there have been 40 classes of training comprised on 287 participants. Each participant have filled out an evaluation scheme which has formed the basis of my evaluation of simulator training. The performed simulator training shows to increase the general downhole understanding of participants and it is an important risk reducing action for Statoil. Feedback from participants shows that mud engineers, drilling engineers and cementers easily become passive observer’s during training. It is proposed to define specific tasks for each participant which will contribute to more engagement throughout the team. With 95,2 % of all participants expressing a desire to come back for further simulator training, is this initiative proving to be attractive among the participants.

Acknowledgement

This master thesis concludes five years of study at University of Stavanger, UIS. The study program is Mater of Science in Industrial Economy, with specialization within contract administration.

This thesis is written for UIS, in cooperation with Statoil ASA, Stavanger. The target audience of this thesis is assumed to have a basic technical drilling and well background.

I would like to thank my supervisors, Dag Ove Molde at Statoil ASA, and Steinar Evje at UIS for input and proposals in how to approach my evaluation of a full scale drilling simulator. I would also like to thank Morten Svendsen, eDrilling, for providing me relevant information and data from simulator training. Appreciation is also expressed to Svein Hovland, Statoil ASA, for always taking the time to answer my questions.

I would also give a special thanks to my girlfriend, Hanne, for being so patient and helpful throughout my studies at UIS.

Finally, I would like to thank my fellow students and future colleagues, Morten Dommersnes and Joar Grimsrud, for our discussions we`ve had throughout the semester.

Bernt-Andrè Lorentsen

Table of Contents

List of tables

List of figures

1. Introduction

Drilling after oil and gas will always be associated with the risk of well control incidents causing hazards to personnel, equipment and environment. One of the main tasks to the drill crew is to *detect* → *react* → *recover* an incident prior to critical situations arises. Hence, a major part of well control incidents that have occurred throughout the years are due to human errors [1]. This can be explained by misinterpretation of signals and/or that policies and procedures within companies are not followed. Operations that are not seen as routine work will require training to sustain knowledge and handling of operational challenges in order to avoid well control incidents. Well control incidents can expose the rig personnel and environment to unwanted circumstances, which both BP`s Macondo incident in the Gulf of Mexico and Statoil`s Gullfaks C-6 incident in the North Sea illustrates as good examples. However, a well-trained drill crew can ensure that reactions and actions on well control incidents will be in accordance with procedures and policies within a company.

In the period 2007-2008 Statoil experienced several serious incidents, and the investigation of the incidents shows that the same causal relation was grouped into the following main areas:

- Deficient compliance with governing documentation
- Deficient risk management
- Deficient leadership

As a consequence, Statoil decided to examine the possibility of developing a full scale drilling simulator that enables safe training at a low cost without disturbing ongoing operations offshore. Statoil`s ambition is to improve risk handling, increase efficiency of work processes and to ensure continued development of leadership skills. Through this there is a potential of reducing necessary training hours offshore, and to build up confidence to drilling & well personnel prior to demanding operations that is to be executed offshore.

Statoil have performed 40 training classes so far this year (January 2012 - June 2012), which is divided on six different licenses. The team compositions have varied, but the key personnel have always been present. In this context will key personnel be the decision makers seen offshore during operation.

This master thesis evaluates the full scale drilling simulator with emphasize on the following aspects:

- Detailed description of the simulator
- The objective with this kind of training
- Evaluation of feedback from participants.
- Comparison of simulator calculations
- How the training is organized
- Who is attending
- Look into the potential of simulator training in Managed Pressure Drilling mode.

The thesis is build up as follows:

- *Chapter 2* gives an general introduction to conventional drilling which is the basis for all simulator training performed during the period I`ve been writing my thesis.
- *Chapter 3* is a literature study of Managed Pressure Drilling (MPD) in general. Simulator training on MPD operations is seen as one of the most important modules that is to be implemented. As part of the thesis I`ve also looked into the potential of simulator training in MPD mode.
- *Chapter 4* gives a brief introduction to typical drilling problems that can arise during drilling operations, both for conventional drilling and MPD. The described problems are highly relevant for simulator training.
- *Chapter 5* gives a detailed description of the Full Scale Drilling Simulator setup.
- *Chapter 6* gives a brief description over the modules that is/will be implemented in the simulator.
- *Chapter 7* is a case study where the different simulation tools are compared with each other. Finally the simulated results are compared with real-time results.
- *Chapter 8* presents the results from evaluation schemes that have been handed out to all participants of simulator training.
- *Chapter 9* presents an overall summary and conclusion of the emphasized aspects of this thesis.

2. Conventional drilling

The drilling technology has evolved over the years. The main drivers for the technology development are the ever increasing demand for energy and the increase in energy prices. Due to technological developments and market opportunities, the oil industry has the opportunity to explore new areas and re-evaluate areas that have been considered as uneconomical and/or impossible due to technological constraints in a safer and more efficient way.

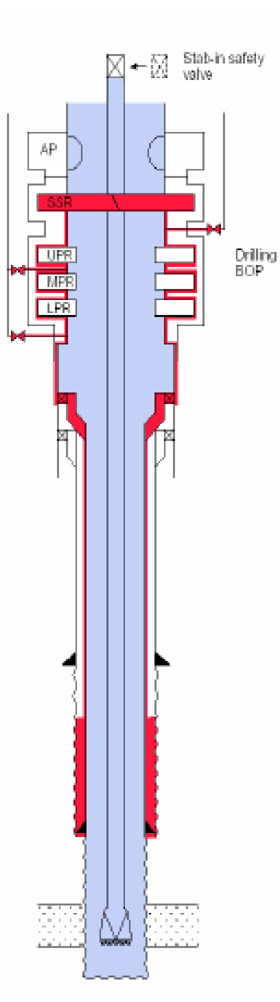
To accomplish the objective of making an optimal well that will maximize hydrocarbon flow from reservoir to surface, there are elements that need to be executed along the way. One of the most important tasks for a license holder is to ensure safe and cost effective operations within a given budget. This implies e.g. selection of efficient drill bits, optimal well path to reach target depth (TD) and correct selection of drilling fluids to optimize production and to obtain well control throughout the well in order to reach target depth within the scheduled time. To ensure effective and controlled operations without serious incidents, the competence and practice of rig personnel needs to be trained.

Conventional drilling operations in the North Sea are today performed in an open vessel that is open to the atmosphere (wellbore and mud pit). According to NORSOK D-010 are drilling fluids the primary barrier element during drilling, see Figure 1. As a primary barrier shall the hydrostatic pressure at all times be equal to the estimated or measured pore/reservoir pressure, plus a defined safety margin [2]. Except being a primary barrier element concerning well control will fluid selection be one of the most critical elements in order to succeed with the planned well design within scheduled time. The primary objectives of a drilling fluid are:

- cooling effect on the bit
- maintain wellbore stability
- optimizing rate of penetration (ROP) and overall drilling efficiency
- reducing non-productive time (NPT)
- minimizing HSE footprint

In addition, selection of drilling fluid for an applicable reservoir section should be based on an evaluation of the possible impact on well productivity (skin effect).

5) Drilling, coring or tripping – Shearable drill string



1) Well barrier elements	See Table *2)*	*3)* Comments
Primary well barrier		
1. Fluid column	1	
Secondary wellbarrier		
1. Casing cement	22	
2. Casing	2	Last casing set
3. Wellhead	5	
4. High pressure riser	26	If installed
5. Drilling BOP	4	

4) Note

Legend:

1. *This describes the name of the WBE(s)*
2. *A complete description of general acceptance criteria for this WBE is found in Clause 15 which contains a library of WBE acceptance criteria tables.*
3. *This table column is used to describe comments.*
4. *The place can be used for describing additional requirements and guidelines. For example a description of compensative measures if there exist common WBEs.*
5. *The illustration shows the primary well barrier in its normal working stage, while the secondary well barrier is shown in its ultimate stage. This stage often described with a closed shearing device.*

Figure 1: Well Barrier schematics for drilling, coring or tripping with a shearable drill string [2].

Conventional drilling circulation flow path begins in the mud pit where the drilling fluid is pumped downhole through the drill string and out through the bit. The fluid flow pumped through the bit flows then up the annulus throughout the wellbore to the atmosphere via a bell nipple, then through a flowline to mud/gas separation and shakers before it is diverted back to the mud pit. The flow loop is shown below in Figure 2.

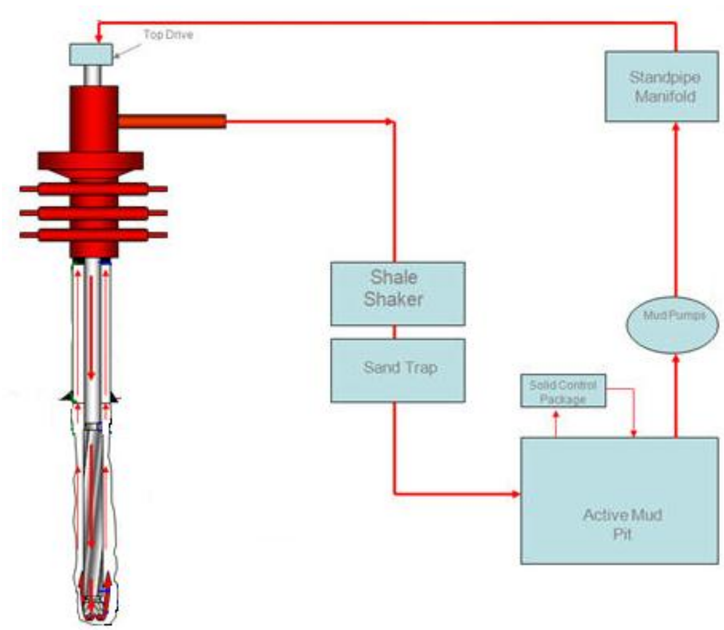


Figure 2: Circulation path during conventional drilling [3].

On a general basis are conventional drilled wells drilled in overbalance. Overbalance can be defined as the condition where the pressure exerted in the wellbore is greater than the pore pressure in any part of the exposed formations, $P_{HYD} \geq P_{BH}$. Bottomhole pressure (BHP) is controlled primarily by adjustments of mud density and/or mud pump flow rates:

During connection the circulation stops and hence static condition arises with annular friction, $P_{AF,}$ assumed to be equal to zero:

$$BHP_{STAT} = MW_{HH} \quad \text{(Eq. 1)}$$

Where,

BHP_{STAT} = Static bottomhole pressure
MW_{HH} = Hydrostatic head of drilling fluid.

However, when the mud pumps are active an addition P_{AF} contribute to increased pressure downhole:

$$BHP_{DYN} = MW_{HH} + P_{AF} \quad \text{(Eq. 2)}$$

Where,

BHP_{DYN} = Dynamic bottomhole pressure
MW_{HH} = Hydrostatic head of drilling fluid
P_{AF} = Annular friction pressure.

Pressure fluctuation is illustrated in Figure 3.

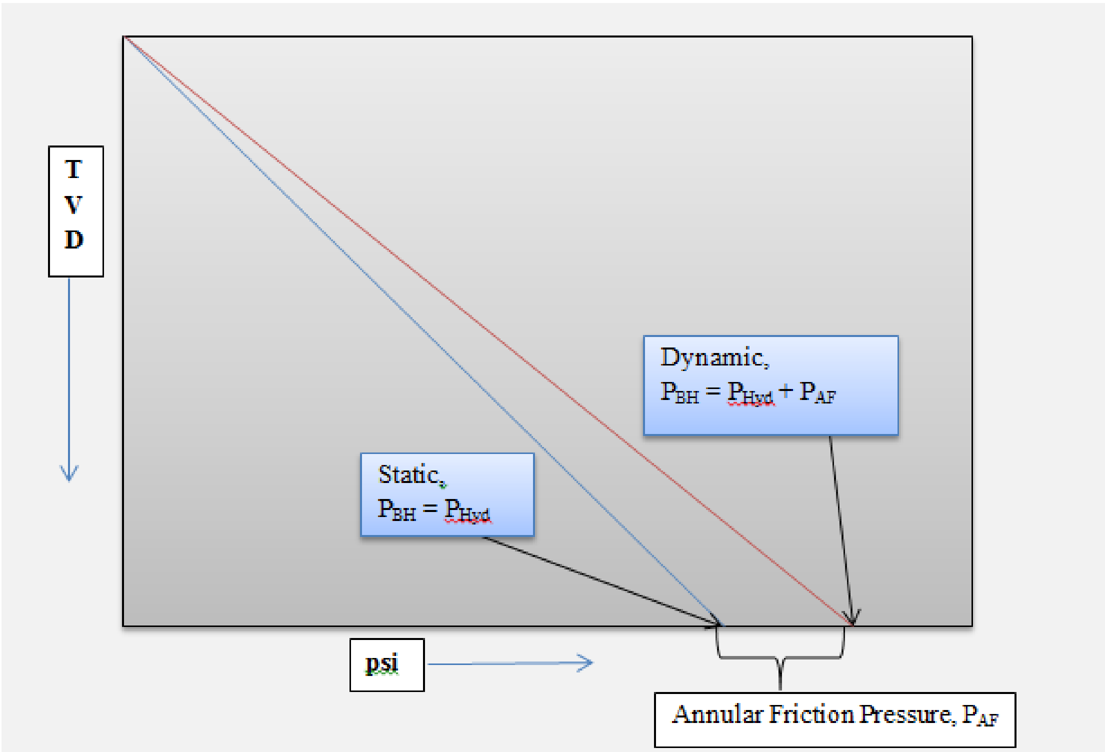


Figure 3: Bottomhole pressure illustrated in static and dynamic condition.

The annular friction pressure is positively correlated to the pump rate, and is created by the motion of drilling fluid as it moves along the various bores along the entire wellbore. However, start/stop of mud pumps during pipe connections creates pressure fluctuations in the wellbore that can cause problems when drilling wells with narrow margins between pore- and fracture pressure.

Another term describing the pressure in the wellbore with dynamic conditions is Equivalent Circulating Density (ECD). ECD is defined as the pressure at any given depth expressed in terms of mud density at a given true vertical depth (TVD):

$$\text{ECD} = ESD + \frac{\Delta P_{AF}}{0{,}0981 * TVD} \quad \text{(Eq. 3)}$$

Where,

ESD: Equivalent Static Density [s.g.], ESD = $\rho g H_{TVD}$

ΔP_{AF}: Frictional pressure loss [bar]

TVD: True Vertical Depth [m].

Conventional drilling has a superior objective to drill the well within the pressure window bounded by the pore pressure on the left side and the fracture pressure on the right side as shown in Figure 4.

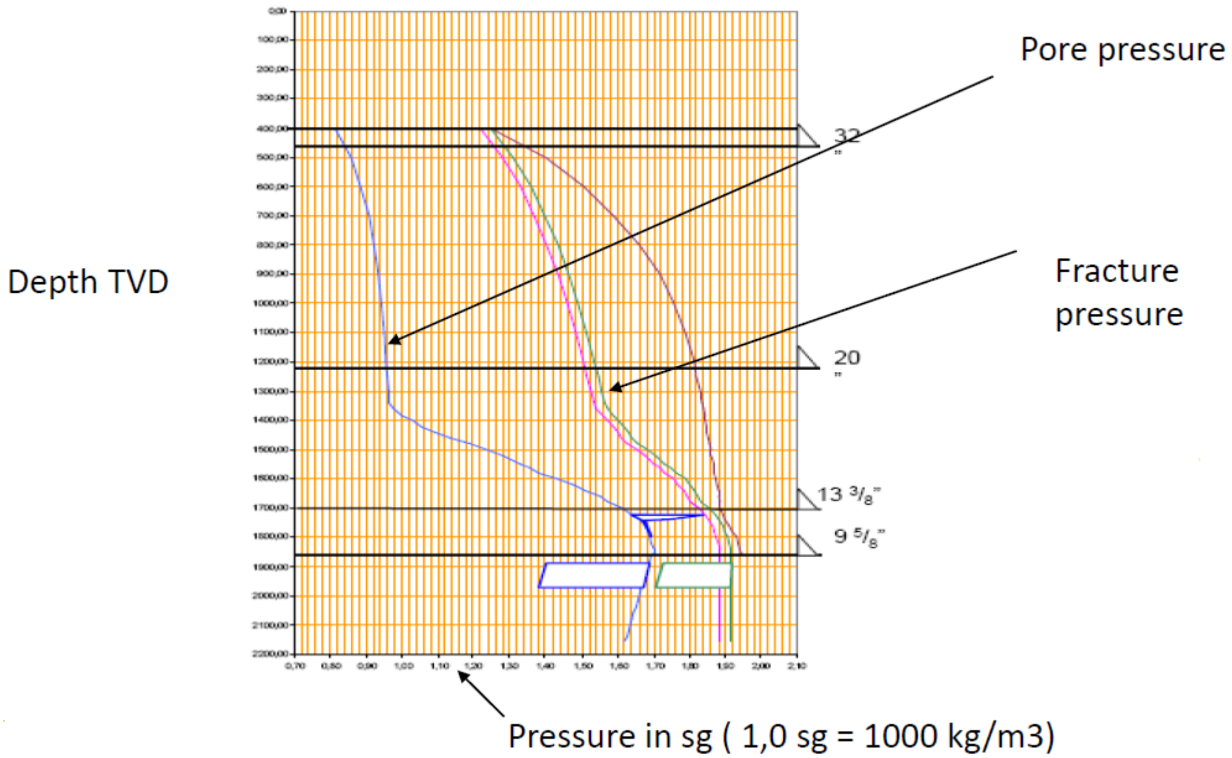


Figure 4: Illustration of reservoir pressure prognosis plot.

3. Managed Pressure Drilling system in general

Managed Pressure Drilling (MPD) technology is a technique that is intended to drill "un-drillable" prospects and reduce the Non Productive Time (NPT) making prospects economically feasible. According to the Underbalanced and Managed Pressure Drilling Committee of the International Association of Drilling Contractors is MPD defined as the following:

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 profile properly. The intention of MPD is to avoid continuous influx of formation fluids to the surface. Any influx incidental to the operation will be safely contained using an appropriate process".

- *MPD process employs a collection of tools and techniques which may mitigate the risks and costs associated with drilling wells that have narrow downhole environmental limits, by proactively managing the annular hydraulic pressure profile.*
- *MPD may include control of back pressure, fluid density, fluid rheology, annular fluid level, circulating friction, and hole geometry, or combinations thereof.*
- *MPD may allow faster corrective action to deal with observed pressure variations. The ability to dynamically control annular pressure facilitates drilling of what might otherwise be economically unattainable prospects.*

MPD is referred to as an adaptive process with not only changeable drilling plans, but the plan will change as the wellbore condition changes during drilling. The word *adaptive* is the keyword as MPD prepares the operation to change to meet pressure profile objectives while drilling. The basic techniques covered under MPD are [4]:

- *Constant bottom-hole pressure* (CBHP) is the term generally used to describe actions taken to correct or reduce the effect of circulating friction loss or equivalent circulating density (ECD) in an effort to stay within the limits imposed by the pore pressure and fracture pressure.
- *Pressurized mud-cap drilling* (PMCD) refers to drilling without returns to the surface and with a full annular fluid column maintained above a formation that is taking injected fluid and drilled cuttings. The annular fluid column requires an impressed and observable surface pressure to balance the down-hole pressure. It is a technique to safely drill with total lost returns.
- *Dual gradient* (DG) is the general term for a number of different approaches to control the up-hole annular pressure by managing ECD in deep-water marine drilling.
- *Continuous Circulation System (CCS)* is applied when challenging formations are encountered. CCS maintains uninterrupted circulation during connection, and hence minimizes the positive and negative pressure surges associated with making a connection under normal drilling conditions.

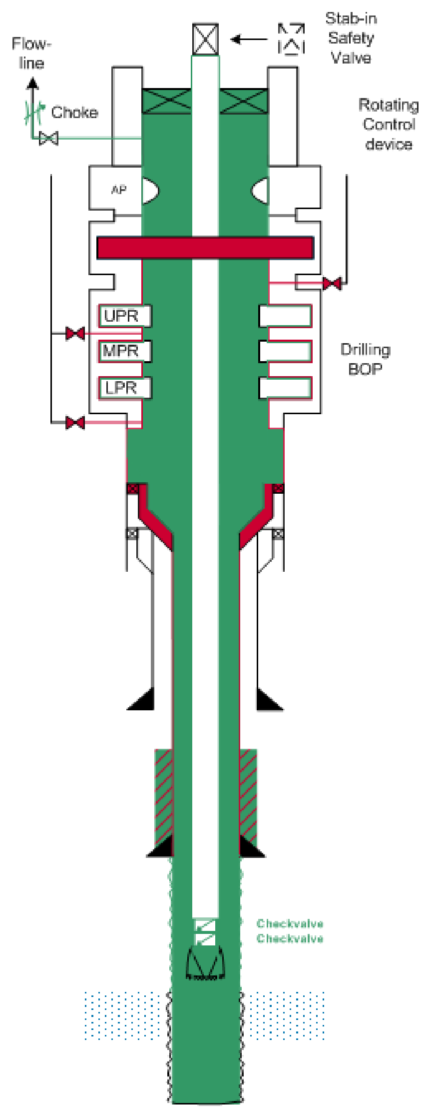
To meet the world`s increasing demand for energy and to find new resources, petroleum production companies must search for new resources in harsher environments and more mature fields. Mature fields offer the challenges of high pressure zones due to water injection and the opposite challenge with depleted zones that are technically difficult to drill. Today we see an increasingly activity in deepwater drilling where very small operational margins are pronounced. NORSOK D-010 defines deep-water drilling as drilling operations that are carried out with water depth exceeding 600m. By applying conventional drilling in deep water wells, one will easily run out of casing sizes without reaching target depth. By introducing Managed Pressure Drilling the wellbore pressure can be controlled within drilling window, allowing the option to set casing seats at greater depths and thereby reducing the total number of casing sizes.

The drivers for MPD applications are to solve drilling problems and increase the understanding of the reservoir. Managed Pressure Drilling has a great potential to overcome challenges with "un-drillable" prospects in problem zones like: depleted zones, abnormal pressure formations, unstable formations with very narrow operational margins, Equivalent Mud Weight (EMW) challenges in Extended Reach Developments (ERD) and enabling dynamically finger printing of pore- and fracture pressures throughout the wellbore.

Another aspect of MPD is the level of safety that is competitive with conventional drilling techniques and that problem wells are being drilled and completed instead of labeled as "un-drillable". However, Figure 5 illustrates that several of the barrier elements in MPD operations are common barrier elements. A common well barrier element is defined as a barrier element that is shared between primary and secondary barrier [2]. The consequence of having common barrier elements is that if one loses the primary barrier envelope, will also the secondary barrier envelope be lost which can cause serious well control incidents. This is a weak point for MPD operations that consequently will require a strong focus during operation.

WELL BARRIER SCHEMATIC

13.8.1 Drilling and tripping of work string in UB fluid



Well data			
Installation:		xxxxx	
Well no:		xx/xx-xx	
Well type:		Oil producer, water injector, gas lift, HPHT exploration etc.	
Revision no:	x	Date:	xx.xx.xxxx
Prepared:		xxxxx	
Verified:		xxxxx	

Well barrier elements	Ref. WBEAC tables	Verification of barrier elements
PRIMARY		
1. Fluid column	1	
2. Casing cement	22	Common WBE
3. Casing	2	Common WBE
4. Wellhead	5	Common WBE
5. High pressure riser	26	Common WBE
6. Drilling BOP	4	Common WBE
7. Rotating control device	48	
8. Drilling non-return valves	50	
9. Drill string or completion string	3 25	Above NRV.
10. UBO/MPO choke system	55	
SECONDARY		
1. Casing cement	22	
2. Casing	2	
3. Wellhead	5	
4. High pressure riser	26	
5. Drilling BOP	4	Shear seal ram.

Notes:

1. The well control configuration described is for rig-up on installations with a surface drilling BOP.
2. The work string refers to drill string (illustrated) or completion string.
3. Stab-in safety valve is readily available on the drill floor at all time with relevant connections.
4. For common WBEs, a risk analysis shall be performed and risk reducing/mitigation measures applied to reduce the risk as low as reasonable practicable.

Disp. no. well integrity issues	Comment
None	

Figure 5: Well barrier schematic for drilling and tripping in MPD/UBD mode [5].

In order to establish well control during drilling, the annular hydraulic pressure profile of the exposed wellbore needs to be managed. The various technologies available today allow us to control bottomhole pressures from the surface within a range of 30 – 50 psi from the ideal pressure that is planned for. The main purpose of MPD is to increase drilling operations efficiencies and to mitigate drilling hazards like:

- Lost circulation
- Stuck pipe
- Wellbore instability
- Well control incidents (kick)

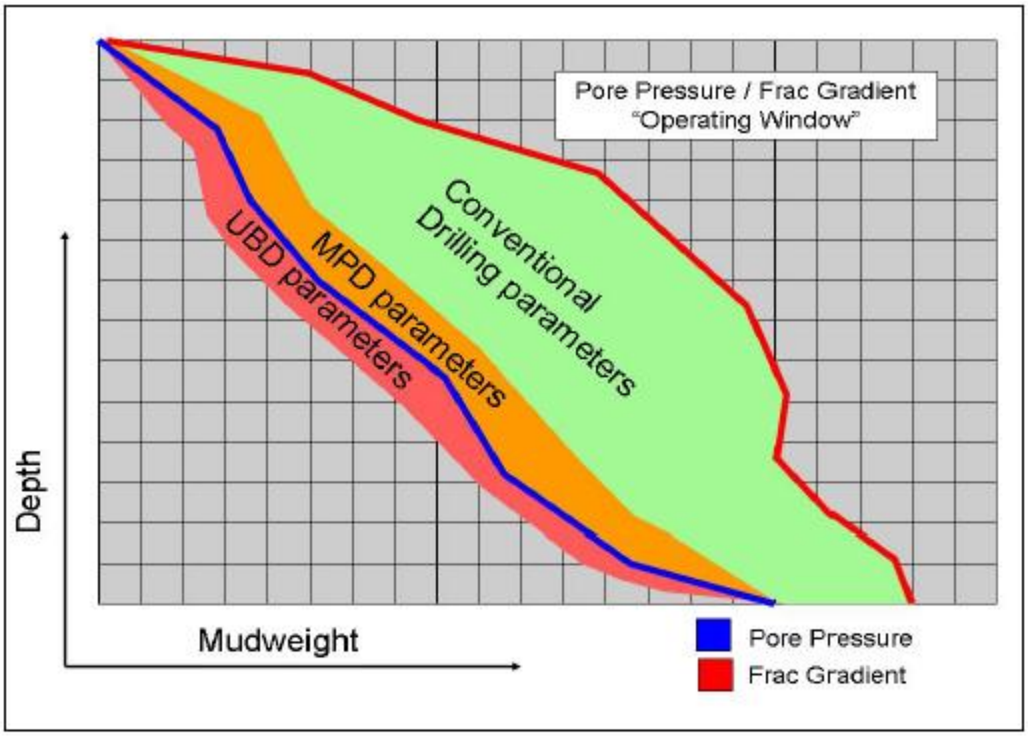


Figure 6: Drilling window for conventional drilling, MPD and underbalanced drilling operations [6].

3.1 Drilling Hydraulics

Factors affecting bottom-hole pressure and causing it to fluctuate during drilling, tripping and connections are mostly due to hydraulic parameters. In order to control pressure fluctuations down-hole, one need to understand the determining factors for pressure behavior in the wellbore. Parameters affecting down-hole pressure are [6]:

- Rheology
- Pump rate
- ROP
- Density
- Geometry
- Surface backpressure
- Compressibility
- Pipe rotation/movement
- Eccentricity

Wellbore instability occurs when the hydrostatic pressure of the mud column is insufficient to maintain bottom-hole pressure within pore- and fracture pressure window. However, during connections the annular friction pressure, P_{AF}, is zero. Hence, during a connection the hydrostatic mud column is controlling the bottom-hole pressure alone. Since the mud weight will remain the same during connection, the absence of P_{AF} shows that the bottom-hole pressure will fluctuate between static and dynamic pressure during each connection. If there is a marginal drilling window between fracture pressure and pore pressure, there is a risk of weakening the formation. How this stress cycle influence the formation depends on the formations properties. Formations with good porosity and permeability have a higher risk of formation weakening, as the formation will change between pressure charged and pressure discharged. This cycle of charging/discharging can induce fatigue to the in-situ formation and ultimately cause tensile failure.

Temperature effect needs to be taken into account when determining mud properties and selecting mud weight for a given interval to be drilled. Thermal expansion in both water-based and oil-based mud can lead to a lower bottom-hole pressure than Eq. 3 calculates, especially in oil or invert emulsion drilling fluid. Thus, thermal expansion can be overspent by a heavy oil-base drilling fluid causing compression of oil and thereby increasing bottom-hole pressure [4].

Another element causing pressure fluctuation in the bottom-hole is drill-pipe movement on connections and trips. Downward movement of drill-pipe causes an increased pressure along the wellbore due to the added ECD push force that comes into account. This is referred to as a *pressure surge*. Upward movements have an opposite effect, thus decreasing the pressure below the bit due to a *pressure swab* effect. This is due to that drilling fluid must flow down past the collar string and bit to fill the hole.

The purpose of MPD is to maintain annular pressure within an operational window to prevent problems. The pressure should be controlled during drilling, connection and tripping. Keeping constant BHP during connection can be achieved by maintaining ECD when the rig pumps are off through the use of continuous circulation system, or by applying back pressure to the fluid in the annulus by restricting its flow through a choke manifold. Further description of how MPD solves the challenges with stable bottom-hole pressure during drilling, connection and tripping will be described in the next chapters.

3.2 Pressure control

Generally, the MPD method known as *constant bottom-hole pressure* refers to a process whereby the annular pressure in a well is held constant or near constant at a specific depth, with the rig pumps on or off. In this context, constant bottom-hole pressure means maintaining the BHP within a window bounded by an upper and lower pressure limit [4].

With applied use of Managed Pressure Drilling technique, the bottom-hole pressure is affected by both hydrostatic weight and annular frictional pressure, but additionally there is an applied back-pressure (BP) from surface. The applied back-pressure maintains the overbalance of the well within its limits:

$$BHP_{DYN} = MW_{HH} + P_{AF} + BP \qquad \text{(Eq. 4)}$$

Without changes to the mud weight prior to connections, back pressure must be applied to compensate for reduced P_{AF} in each connection. Hence, back pressure is normally applied in the transition from dynamic to static (and opposite) as the mud pumps are tuned down until static condition is valid.

3.3 MPD equipment

The source for this chapter is [7] unless otherwise is stated in the text.

Managed Pressure Drilling operations requires a certain amount of equipment in order to be applied. Since there are different MPD applications there are different requirements, and this section will focus on Halliburton`s MPD setup that is to be implemented in the simulator. Halliburtons GeoBalance Autochoke unit, Back Pressure Pump, Metering skid unit and advanced automated control system run in conjunction with a field proven transient hydraulics model, are designed to accurately maintain BHP within a +/- 2.5 bar operational window [7].

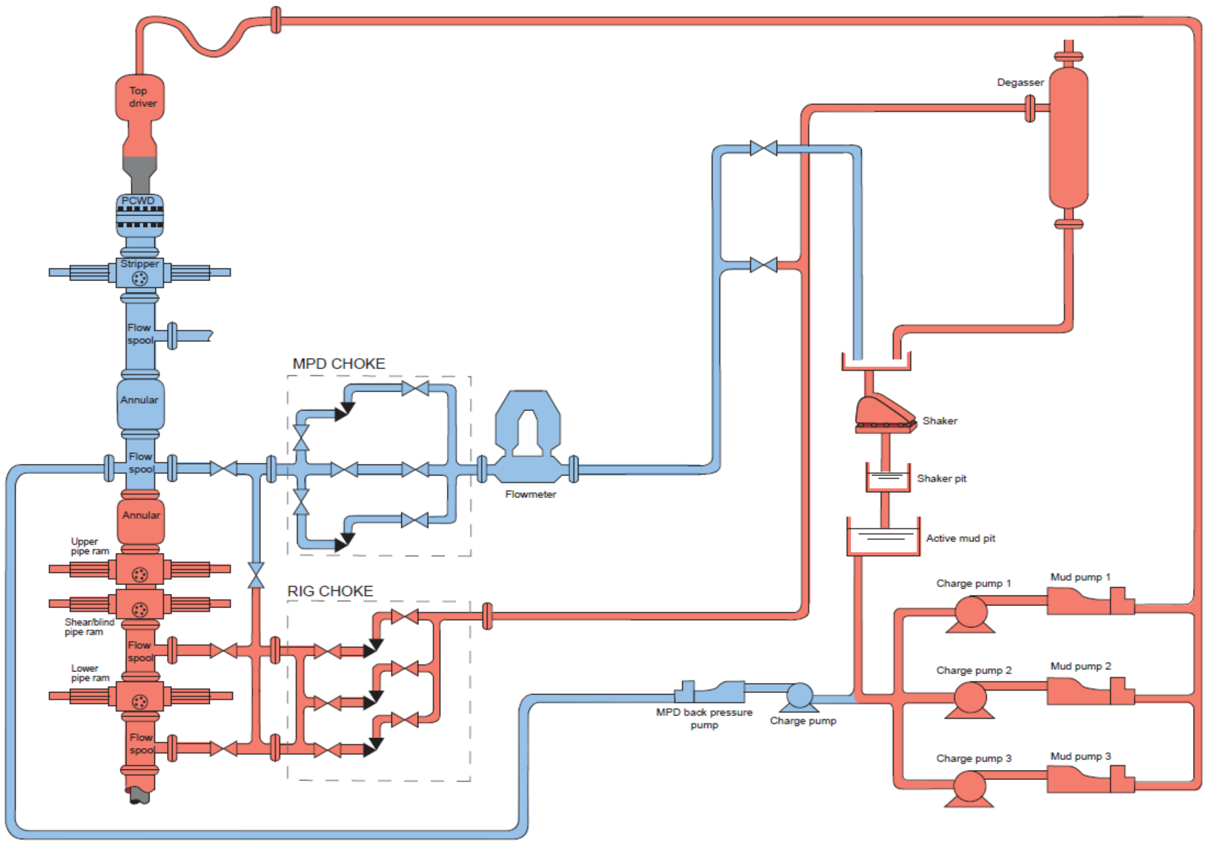


Figure 7: Example of MPD setup on a fixed platform [7].

3.3.1 Automated Choke Manifold

The main objective with MPD operations is to control wellhead pressure (WHP) and thereby accurately control the bottom hole pressure (BHP). The automated choke manifold is controlled by an advanced transient hydraulics model, where the inputs to the software are based on the measurement readings from the service provider and a third party data.

The unit`s choke manifold and dual chokes are rated for drilling mud flow with associated drilled cuttings, mud additives and formation fluid. The two chokes are lined up in parallel for redundancy in case of maintenance and/or repair of one of the chokes without interrupting the operation. Thus, enabling remotely isolation by dual block valves installed both upstream and downstream of the chokes. The manifold also incorporates chemical injection capability. The automated chokes can also be manually operated and adjusted from a control panel on the unit.

Instrumentation on the automated choke manifold includes pressure and temperature both upstream and downstream of operational chokes, with recordings of data.

Halliburtons GeoBalance Autochoke Unit is shown below, see Figure 8 and Figure 9.

Figure 8: GeoBalance Autochoke Unit.

Figure 9: GeoBalance Autochoke instrumentation.

3.3.2 Flow Metering Unit

The Coriolis mass flowmeter is an important part of flow measurements in MPD operations. A Coriolis flowmeter measures mass flow, volumetric flow, temperature and density. The Coriolis meter is a very accurate method of measuring drilling fluids while taking into account drill cuttings that tends to interfere with other types of flowmeters [4]. The accuracies of the Coriolis meter is a few ten-thousandths of a gram per cubic centimeter.

Generally, the system works as follows [4]:

- Dual parallel flow tubes, U- tubes, are oscillated in opposition to each other at their natural frequency by a magnet and a coil.
- Magnet and coil assemblies are mounted on the inlet and outlet side of the parallel flow tubes with the magnets on one tube and the coils on the other.
- The vibration of the tubes causes the coil output to be a sine wave that represents the motion of one tube relative to the other.
- When there is no flow, the sine waves from the input and output coils coincide.
- The Coriolis effect from a mass flow through the inlet side of the tubes resists the vibration. The Coriolis effect from the mass flow through the outlet side of the tubes adds to the vibration.
- The phase difference between the signal from the input and output sides is used to calculate mass flow.
- Frequency change from the natural frequency indicates density change, while increasing mass density decreases frequency.
- Volume flow is mass flow divided by density
- Direct temperature measurement is used to correct for temperature changes.

Halliburton`s Coriolis flowmeter have an flow rate measurement range of 0 to 3500 lpm at fluid temperatures up to 120˚C. Thus, the flowmeter provides four critical data parameters for the automated choke system, and for the MPD operators on the rig monitoring the well and operation.

If the flowmeter becomes plugged with debris, the Pressure Safety Valve (PSV) will relieve upstream flow to a dedicated atmospheric PSV tank. The plugging of flowmeter can be caused by drilled solids or RCD sealing element material.

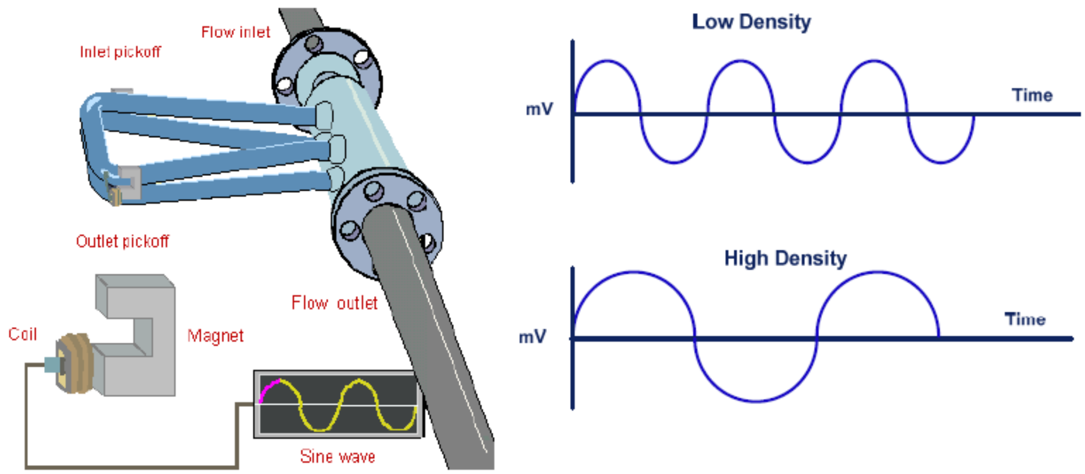


Figure 10: Coriolis flowmeter with oscillation period [6].

3.3.3 Back Pressure Pump

Back pressure pumps (BPP) are used to ensure minimal BHP fluctuations during all parts of Automated Choke MPD operations. The BPP is tied into the flow spool under the Rotating Control Device, allowing injection of drilling fluid across the well head with return to the automated choke unit. The BPP is actuated when the rig pumps are switched off during connection and tripping in order to maintain the annular pressure in the well. Illustration of BPP is shown in Figure 12 and Figure 13. As mentioned will applied back pressure during connections reduce the cyclic pressure seen down hole, reducing the risk of fatigue problems to the formation, see Figure 12 and Figure 13.

Flow from the BPP, and the resulting back pressure seen is maintained and controlled manually or automatically by the choke unit. The maintenance is carried out in the same manner as regular MPD circulation with rig pumps.

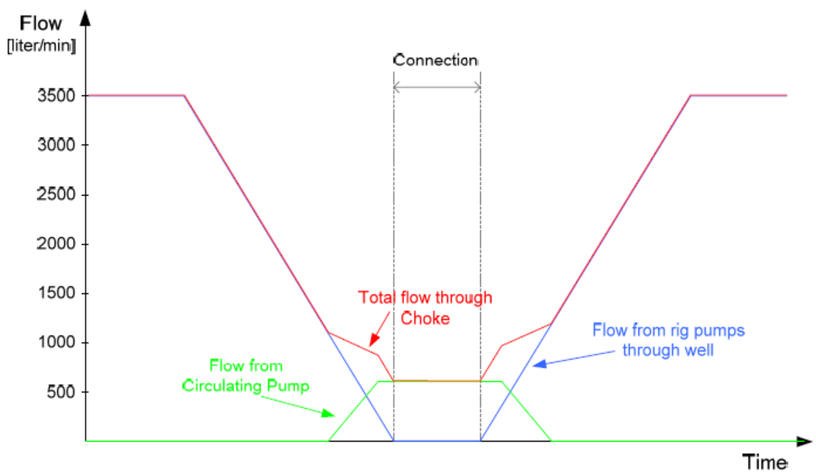


Figure 11: Flow during a connection in MPD mode with BPP [5].

Figure 12: Halliburton`s Back Pressure Pump (1).

Figure 13: Halliburton`s Back Pressure Pump (2).

3.3.4 Rotating Control Device

The Rotating Control Device (RCD) is used to divert the flow (flow spool) to the choke manifold in addition to seal the well bore during operation. RCD consists of a rotating sealing element “stripper rubber” which is ½” in. to 7/8” in. diameter undersize to the drill pipe and is force fit onto the pipe. The rubber element rotates with the drill pipe and allows the pipe to enter and exit the wellbore whilst maintaining the pressure in annulus. With increased annulus pressure, the rubber element exerts an increased force against the pipe (Pressure x Unit-area). Thus, the driller doesn`t need to take any action during drilling or stripping. As the stripper elements are mounted in the bearing assembly, the bearing pack is lubricated and cooled by a circulating hydraulic oil system. This provides a closed circulation system, preventing exposure of toxic gases on the drill floor while the BOP is actuated.

The basic system used can be divided into two categories, the passive rotating control device and the active rotating annular preventer. The former is the one described above.

Rotating Annular Preventor is the active system that uses hydraulic power to be actuated. One example of this is the pressure-control-while-drilling (PCWD) rotating annular preventer shown in the illustration below, see Figure 14 and Figure 15.

Figure 14: Rotating Control Device [8].

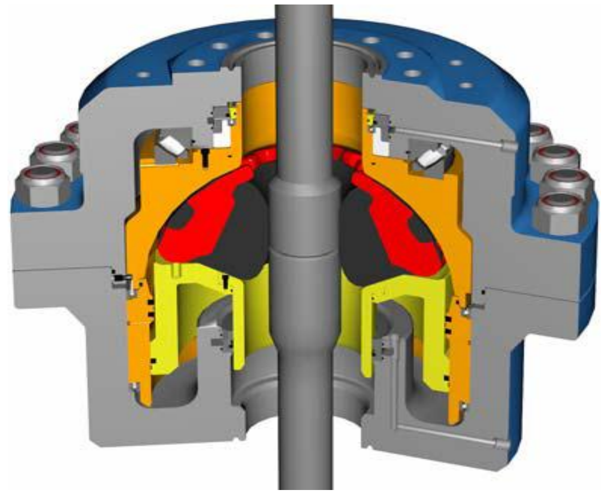


Figure 15: Active rotating annular preventer [8].

3.3.5 Control Cabin and Control System

The control cabin functions as an MPD Operations Command Centre, and houses the Automated Control Systems and Insite Data Acquisition System (DAS). MPD Control System and Insite DAS provide the dynamic hydraulic models.

The MPD operator will monitor all surface recorded parameters in the control cabin where adjustments to chokes and calibration of hydraulic models are continuously evaluated. The MPD operator in control cabin (Figure 16 and 17) receives real-time data from third party companies, including mud logging, MWD and Rig system data in the work to optimize the drilling operation.

Figure 16: Halliburton`s Control Cabin.

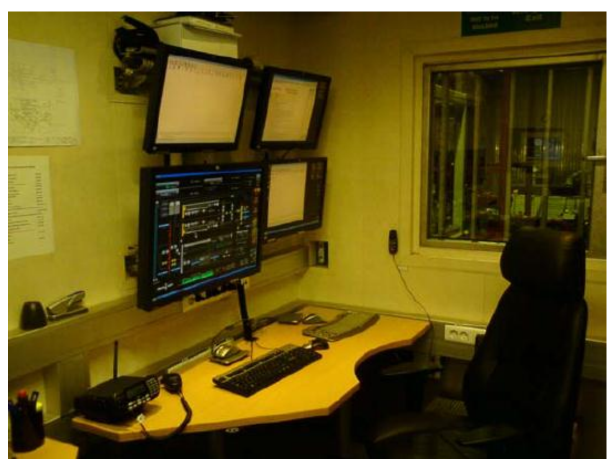


Figure 17: Inside Halliburton`s Control Cabin.

3.3.6 Continuous Circulation System

The development of a Continuous Circulation System (CCS) enables sections to be drilled without interrupting circulation during connections. As shown in Figure 18 and Figure 19, the coupler is function as a pressure chamber located above the rotary table. The drill pipe passes and which seals around the drill pipe pin and box end during the connection process. During a connection, drilling fluid is circulated into the chamber and pressurized to circulation pressure. The pressure is equalized inside and outside the drill pipe, then the connection is broken and the tool joint pin backed out and raised clear of the box. The pressure chamber is divided into two sections by a sealing device which allows pressure to be bled off in the upper chamber while still retaining circulation below which then allows the pin connection to be removed. The new joint of drill pipe is then run into the upper chamber, which is sealed and re-pressured with drilling fluid from the circulation system. With pressure equalized, the dividing seal is opened and the new drill pipe joint lowered and the connection made up with circulation continuing through the drill string. As a final step the pressure in the chamber is bled off, and the seals are opened and drilling can continue [9].

CCS has a potential to be beneficial in the following operations:

- Extended Reach Drilling (ERD) – Horizontal wells
- Deep-water wells
- Underbalanced drilling
- Narrow pore pressure/fracture pressure
- Pressure sensitive wells
- Circulate/Drill-in liners
- Safety (reduced risk of taking kicks)

Figure 18: Main unit of CCS [10].

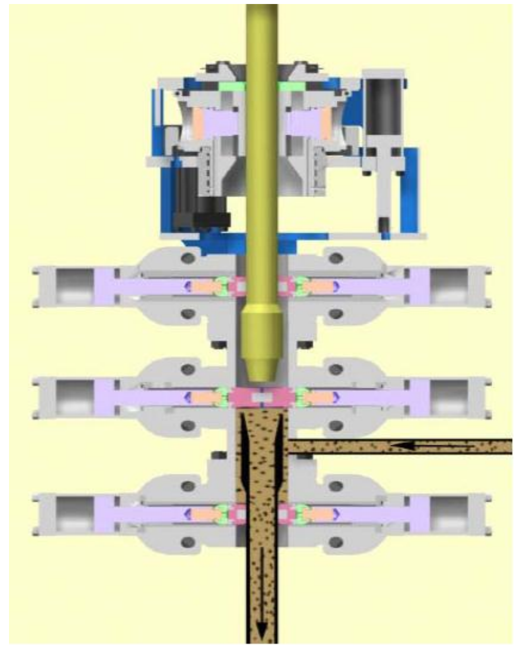


Figure 19: The coupler.

Mud properties changes with temperature and pressure and this can cause challenges in HPHT wells. Designing properties of a drilling fluid can be challenge in environments with high temperatures. Thus, if the drilling fluid is heated above design criteria due to stop of circulation in a connection, the trends and behavior can be hard to interpret. Continuous circulation system enables circulation to continue during connections, and hence will the affection of temperature be reduced due to continuously circulation of fluid. CCS creates the same conditions as during drilling and thereby will temperature fluctuations be reduced and kept within its design limits. For an HSE perspective will CCS also minimize connection gas and avoid settling of cuttings. Hence, installation cost is often preventing CCS to be more implemented in MPD operations than what is sees today [9].

3.4 Economics

The cost of drilling a well can in theory become close to limitless if the drilling operation keeps fighting against lost circulation, stuck pipe, fishing and well control incidents. For some wells can MPD solve the challenges that one face, and thereby enabling the well to be drilled. The cost associated with required rig modification, implementation of MPD equipment's and the cost of training drill crews needs to be compared to the potential upside of succeeding with an drilled well with reduced problems. The potential of reduced costs when applying MPD is related to; reduced NPT (rig cost), reduced mud usage and the profit related to production from the specific well that would not be produced without MPD.

3.5 Human competency

All of the equipment and technology mentioned above is useless without human competence to operate it. As the equipment complexity increases with the development, it is required that personnel receive teaching and training in the use and handling of equipment's procedures and functionality. The technological development goes towards more automation of operations which reduces the risk of human error. However, this is only to a certain degree since decisions are still to be taken. MPD operations are carried out in challenging wells, where mistakes can be catastrophic. Hence, having rig personnel that understand the processes down hole and at the same time are able to handle all kinds of operations at rig site is essential to achieve safe and successful operations. Simulator training in the Full Scale Drilling Simulator will enable realistic MPD training with same functionality as offshore both for normal and contingency operations when a third party MPD service provider is implemented [11]. This gives Statoil and its contractors a great opportunity to be familiar with how the equipment responds to different actions and not least train on different operational procedures and challenges in a safe and quiet environment.

Statoil requires competent personnel for all Managed Pressure Operations (MPO). The personnel in the process of becoming competent shall be supervised by competent personnel, and need to perform training in the following three different steps as a minimum requirement [12]:

<u>Step one:</u>
The following personnel shall complete the e-learning programs "Well Integrity Basic" and "MPO basic":

- Assistant driller
- Driller
- Drilling supervisor
- MPD operator
- MPD supervisor
- Drilling engineer
- Operations geologist
- Wellsite geologist
- Drilling superintendent
- Rig manager
- Platform manager

<u>Step two:</u>
The above personnel (except platform manager) shall attend a field specific classroom course. MPD supervisor shall have valid IADC well control certification.

<u>Step three:</u>
The involved offshore personnel shall perform offshore training before initiating the MPD operation. The offshore training shall include planned operations and contingencies. A plan shall be in place to ensure sufficient training for oncoming crews.

Step one and two shall be refreshed every second year.

Figure 20: Training strategy for MPD operations.

3.6 Potential of simulator training in MPD mode

As described earlier in this chapter requires Managed Pressure Drilling operations some additional equipment compared to conventional drilling. Hence, this requires personnel to be introduced and trained on both interpretations and use of the new devices. MPD operations account for a relatively small proportion of well operations compared to conventional drilling. This makes the knowledge around operational procedures and handling of this type of jobs correspondingly small.

The advantage of being able to conduct training on operations and procedures in a drilling simulator is that the licenses will be able to get a feeling of both response and function of MPD equipment's. As the dynamics of MPO are different from conventional drilling, will performed training in MPD mode provide an improved downhole understanding that will enhance the crew`s ability to handle both routine work and critical situations that arises. The effect of improved competence level throughout the drill crew will be an increased safety level during operations, and it will strengthen the planning of upcoming wells that is to be drilled. Another important potential that distinguishes this type of training from other types of courses/training, is the ability to train the whole team together, including the MPD supplier. This provides a unique opportunity for the team to get to know each other and work out scenarios with a focus on communication within the group. Hence, the personnel that will be trained in MPD mode will be highly competent drilling personnel who have completed interactive training in understanding MPD technology prior to simulator training.

A proposed plan for simulator training in MPD mode is to set aside two days for training, where the first day is used to familiarize with MPD operations/training and the simulator. Day number two is proposed to be used for case training in MPD mode, where the learning's from day number one is practiced. In more detail, the proposed training content should include the following:

- ***Day number one*** should comprise an general introduction to MPD operations with introductions to typical drilling problems and difficulties that is common for MPD mode. The objective with implementation of MPD should be clearly stated and discussions should be provoked about engaging MPD mode, relevant procedures, communication, line up procedures and functional challenges. The mentioned elements should be covered in the theoretical part in the classroom. After finishing classroom activity, the drill crew should be familiarized with the drilling simulator. Familiarization with the simulator should include the use of the simulator, where one goes deeper into the drilling operations and well control scenarios in MPD mode. For drilling operations should elements such as initiation of MPD (displacement of conventional mud to MPD mud), drilling ahead, dynamic effects (RPM, swab/surge, etc.) and connections be covered. A review of the effects caused by RCD during fingerprinting and identifications of pore and fracture pressure by utilizing dynamic flow checks are also important elements to be covered. Concerning well control should the team be introduced and trained on transitions procedures between green, yellow and red. Green, yellow and red are here categories concerning kick/loss volumes.
- ***Day number two*** should comprise an opening with classroom discussions concerning lost circulation, detect – react – recover influx contingencies, casing/liner running operations and RCD element change out. After finishing constructive discussions in the classroom should the team be ready for case training in the drilling simulator. Case training should emphasize lost circulation, influx scenarios, contingencies and/or casing/liner operations with focus on detection, reaction and recovery. Cementing operations are also highly relevant to be trained on.

The proposed MPD training agenda is illustrated in Table 1.

DAY 1	DAY 2
08:30 - 09:00 Arrival and Registration 09:00 - 09:15 Welcome & Introduction 09:15 - 09:45 MPD operations on Gullfaks 09:45 - 10:15 Introduction of Drilling Simulator ➢ Simulator (Instructor) ➢ MPD control system (Halliburton) 10:15 - 10:30 Coffee 10:30 - 12:00 Normal MPD operations ➢ Initiation of MPD (45 min). ➢ Connections: Ramping rig pumps manually and automatically, With and without back pressure pump, Communication between driller and MPD operator (45 min). 12:00 - 12:30 Lunch 12:30 - 15:00 Normal MPD operations ➢ Drilling: Responses on hole cleaning and torque and drag effects (45 min). ➢ Tripping with realistic surge/swab response (30 min). ➢ Displacement operations: Setting balanced mud pill, Displacement of balanced mud pill, Bottom kill, Cementing (45 min). ➢ Liner running and Cementing (30 min). 15:00 – 15:30 Coffee 15:30 - 17:00 Well Control ➢ Influx, Lost circulation (30 min) ➢ Transition from MPD to well control (30 min) ➢ Transition from well control to MPD (30 min). 17:00 – 18:00 Summary ➢ Procedures discussed. ➢ Hazard ➢ Focus areas	08:00 - 09:00 MPD operations on Gullfaks ➢ Review of procedures and hazards ➢ Presentation of well for practice. 09:00 – 11:00 Case 1 (Loss circulation) ➢ Observe decreasing trend in flow out less than 4 m3/hour. ➢ Follow Lost Circulation Guidelines to mitigate losses as per guidelines. • 11:00 - 11:30 Lunch 11:30 - 14:00 Case 2 (Pulling from TD. Run and cement Liner) ➢ Displace to overbalanced fluid ➢ Trip out of hole. ➢ RIH with liner, displace back to underbalanced MPD fluid. ➢ Complete cement operation with MPD control (multiple fluid). 14:00 – 14:30 Coffee 14:30 – 17:00 Case 3 (Contingency) ➢ Surface blockage. ➢ Loss of rig power. ➢ Surface leaks. ➢ Equipment failure. 17:00 - 18:00 Evaluation and Feedback (All) ➢ Evaluation of performance and choices made ➢ Risk evaluation, Detection, Communication ➢ Technical solutions ➢ Fill out evaluation sheet 18:00 End of simulator training

Table 1: Proposed agenda for MPD training

4. Drilling problems

In the following section will typical drilling problems be highlighted. The different problems are supported by the drilling simulator and are applicable for all the five modules the simulator is based on. One of the roles the instructors takes during simulator training is to observe the group`s ability to early "detect – react – recover" according to governing documents under similar operational conditions as seen offshore.

4.1 Lost circulation

Lost circulation is one of the major causes of NPT and occurs when hydraulic pressure at a given point exceeds the formation fracture pressure. Drilling engineers select fluid density out of pore pressure plots, which is an estimated pressure profile of formation based on testing and earlier experience. If the selected drilling fluid exceed formation pressure at a given depth (static and/or dynamic ECD), will the fluid column in drill string and annulus be reduced until equilibrium is achieved. A reduced fluid column in annulus and drill string can be a result of fracturing of formation due to hydrostatic pressure has exceeded fracture pressure in the wellbore. Initiation of fractures in a wellbore enables the fluid to escape out of the wellbore until the pressure in formation at the given depth is equal to hydrostatic pressure in the wellbore. This can cause dangerous and challenging well control situations.

Other causes to lost circulation can be:

- Drilling into natural fractures
- Pack-off due to poor hole cleaning

The drill crew is trained to control the pressure down the hole and will generally respond by shutting down the pumps to identify dynamic or static losses. If static conditions are stable, the pumps are staged up to detect max loss free circulation rate. When max circulation rate is identified, a new formation gradient is established and mud weight is adjusted accordingly. If static losses are seen, the mud weight will be reduced as a contingency and/or LCM material will be pumped to stop leak paths. If severe losses occur, the risk of taking a well kick and/or trip gas arises. Hence attention to mud weight needs to be continuously evaluated to maintain well integrity.

4.2 Well kicks

In order to take a well kick, the following properties of the formation needs to be present:

- Permeability of the formation must be sufficient for a flow to occur
- Pore pressure must be higher than the hydrostatic column of drilling fluid.

Even in the best of all worlds, where a well kick is detected at the opportune time, circulated out of the hole, and the drilling fluid density increased with no difficulty, there are additional costs for time and mud materials. Well kicks will also increase the potential for differential sticking of the drill pipe and lost circulation due to fracturing of formation. The overall cost of well kicks can be a large portion of the drilling budget [4].

Causes to well kicks can be:

- Insufficient mud weight
- Lost circulation
- High pressure zones / pressurized formations
- Swabbing
- Gas cut mud

As mentioned earlier, are well control incidents caused by a major portion of human errors. Hence, it is of great importance that the cause of an incident is detected and understood to be able to prevent/handle similar events.

Since the drilling simulator is not a kick-simulator, the focus of the training is more on a “detect – react - recover” level. The instructor tests the crew on the evaluation process to make a right decision on *how* to solve the situation with emphasize on method selection to re-establish well control. Methods to be considered in order to regain well control are illustrated in Table 2.

Kill method	To be considered
Drillers method	The recommended and preferred method when the well can be circulated at bottom.
Wait & Weight method	An alternative method in vertical wells with long open hole sections where there is a narrow margin between fracture pressure at casing shoe and the required mud pressure.
Volumetric method	In cases where Wait and Weight method or Drillers Method cannot be used effectively. Some cases are illustrated below: • Drill pipe is out of hole of far off bottom and cannot be stripped in • Circulation is not possible • The drill pipe has a leakage • Pumps cannot be operated
Bullheading	Is applicable where other common methods of well control cannot be used effectively. Examples are: • Drill pipe is out of hole of far off bottom and cannot be stripped in • The drill pipe has a leakage • Influx of H_2S • Returns lost when circulating out the kick • Surface pressure or H2S presence would pose a serious risk to the rig and its equipment during normal killing operations.
Dynamic method	Can be used if the bit is at or below producing formation.

Table 2: Response to well kicks [13].

4.3 Differentially stuck drill pipe

Stuck pipe can be a major cost issue, and is often initiated by a well kick or to high mud weight causing a high differential pressure in permeable zones. Differential sticking is caused by the difference in pressure between the well bore and a permeable zone. The explanation of this failure is that the mud filter cake retards the flow of liquid into the lower-pressure permeable zone and the pipe is differential stuck against the wall. By keeping a lower differential pressure between the well bore and the formation, the risk of getting differential stuck will be reduced. [4]

Moreover, succeeding to resolve one well control issue can initiate another issue. Drilling a hole section with a narrow drilling window between the pore - and fracture gradient can cause a kick – lost circulation – kick – diff. stuck scenario which can be challenging to handle. When stuck pipe incidents arise during training in the drilling simulator, the instructor focuses on the response of the drilling personnel on *how* they respond to the case with emphasize on how the communication within the crew and if the important aspects of the situation is highlighted.

Illustrations of the drilling problem scenarios are shown below in Figure 21.

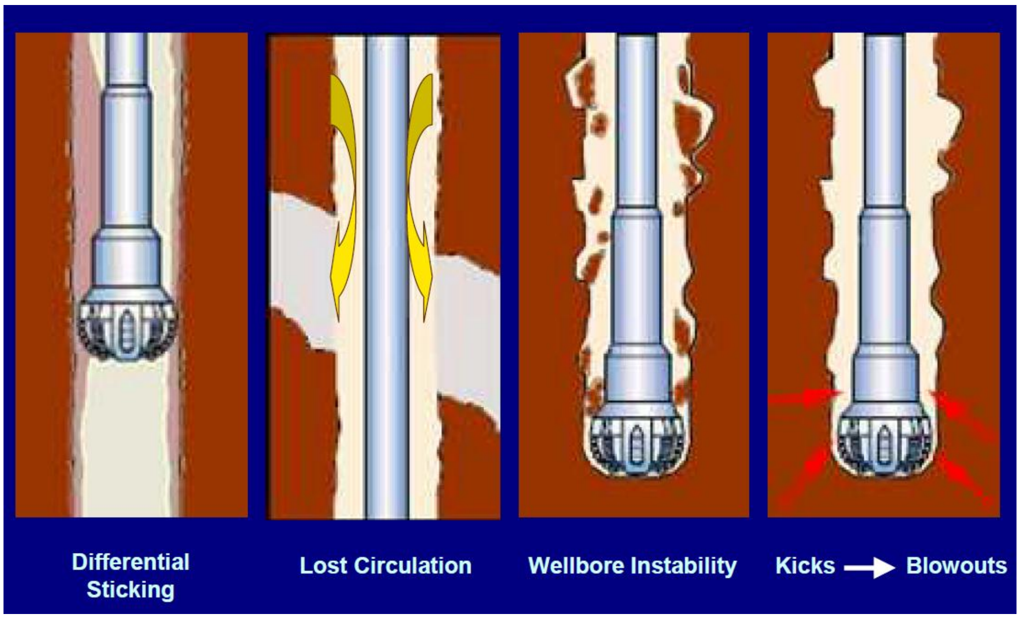


Figure 21: Drilling problems.

4.4 Ballooning

Ballooning can cause significant NPT. Ballooning arises when a formation with plastic behavior has the ability to take some drilling fluid during circulation and return the taken volume when static condition is encountered. For a driller following pit volumes during connection (pumps off) this can easily be understood as a start of a well kick. The driller can choose to monitor well flow to identify whether the volumes are stabilizing or if the well is having an influx and accordingly take a decision to shut-in the well. In order to limit NPT due to ballooning effects, it is important to establish algorithm/procedures to identify correct flow behavior.

4.5 Pressure challenges

4.5.1 High Pressure and High Temperature

Discoveries of oil and gas fields in severe conditions of temperature (above 150°C) and/or pressure above 50 MPa have been made in various regions of the world. This brings important challenges for property prediction of reservoir fluids. The Norwegian Petroleum Directorate defines a well as a High Pressure – High Temperature (HPHT) well if:

- it is deeper than 4000 m, or
- its reservoir pressure exceeds 10 000 psi, or
- the temperature exceeds 150°C.

The described conditions in a HPHT well, shows that the environment is harsher compared to conventional wells. A HPHT well is a critical well, where there are small design margins, and where a well control problem is difficult to handle.

HPHT wells are usually drilled at much longer rig time and higher expenditure than non-HPHT wells, this is due to the high complexity and technical challenges. As far as drilling is concerned, there are several major challenges from HPHT wells [14]:

- The mud must be stable under extreme pressures and temperatures as unstable mud systems can often lead to mud gelation, barite sag and other problems.
- The effects of pressure and temperature on mud weight (MW) and on the equivalent circulating density (ECD) cannot be ignored due to the potential impact.
- Rheology must be optimized to minimize ECD without inducing barite sag.
- The drilling margin or window between pore pressure and fracture gradient becomes significantly narrower. Loss and gain situations can be experienced with a slight error.
- As the mud hydrostatic pressure is very close to the formation overburden pressures, the formation behaves abnormally. The terms used to describe this complex behavior include formation ballooning, plastic formations or formation instability, which makes it more difficult to differentiate a kick from returns of previous downhole losses.

The small margin seen in terms of MW and ECD or rheology in HPHT wells is often complex and problematic. The potentially very narrow pressure margin is the main risk driver in HPHT drilling. The greatest contributors to risk where narrow margins are present are the risks of high swab pressures and tight hole during tripping, mud loss and swab pressure caused by trying to free a stuck liner. [15]

The main focus for training on HPHT wells are influx situations where the focus is on detection, reaction and recovery. The well model gives realistic response to dynamic changes in temperature, both directly and indirectly through fluid temperature dependent properties.

4.5.2 Pressure depletion

Pressure depletion is generally defined as a reduction in the in-situ pore pressure in the formation due to production. A consequence of pressure depletion can be a reduced drilling window due to changes in pore - and/or collapse gradient, and on the other side affection of fracture gradient. On a general basis is drilling in depleted zones not necessarily a problem. Thus, the problems arise when the depletion is unevenly distributed or unknown in the depleted reservoir sections. Another concern to take into account is if production encounters before all planned wells are drilled on a field. This can cause limitations to further drilling of more wells if rapid and significantly reduction in reservoir pressure is a result of production. Thus, early production can be initiated if applicable drilling tools (e.g. MPD) can mitigate/solve the new drilling challenges.

5. Full scale drilling simulator

In August 2010 a frame agreement were established between Statoil and SINTEF Petroleum Research AS for the development and use of the Full Scale Drilling Simulator. The other cooperating partners of the consortium are Oiltec Solutions, eDrilling Solutions and Maersk Training. The responsibilities between the different partners are as follows:

Figure 22: Drilling simulator partners.

The cooperation between Statoil and cooperating companies have resulted in a highly advanced drilling and well simulator which combines a highly developed top-side simulator (hiDRILL) with a superior down-hole simulator (Intellectus). Statoil intends to ensure optimal competence level for its Drilling & Well personnel by offering realistic personnel training on operational procedures and well control incidents in a safe environment, thereby improving both procedures and personnel competence by frequent use and revision. The training is focusing on common and critical drilling & well operations in order to increase operational understanding, improve communication and to develop teams that are better prepared to execute tasks, handle critical situations and to ensure safe and efficient drilling operations according to the Compliance and Leadership model. Training performed in this full scale drilling simulator serves as a supplement to the various courses currently offered to the drill crew.

The full scale drilling simulator is based on a step-by-step process where the Statoil Project Team qualified the downhole models as stand-alone prior to the models was coupled together to one product capable of handling different drilling and well scenarios. The models were qualified and verified both by several in-house software packages and by comparing historical well and operational data with results seen in the simulator. In this respect Snorre A, Snorre B and Gullfaks C have made valuable contribution with the supply of data and verification tests on the simulator together with personnel from these projects.

Statoil`s objective by implementing simulator training is to improve the drill crews ability to identify potential serious hazards early and learn to correct the operation accordingly. Statoil have also the ambition to raise company-wide performance and thus reduce the likelihood of critical situations due to deficient quality and precision in their activities. Thus, simulation and visualization of drilling operations will result in [16]:

- A better understanding of downhole conditions and limitations.
- A better understanding of key drilling parameters and best practices.
- A better handling of field specific challenges.
- Enhanced risk assessment and planning of tasks.
- Enhanced communication between key personnel during critical situations.
- Enhanced execution of well control situations.
- A team that is better prepared to avoid events and to handle critical situations.
- Improvement of efficiency, quality and HSE through better process understanding.

Successful training and improvement of the personnel's action in different scenarios requires realistic cases with a rig setup close to what the personnel is used to. Hence, the simulator is configured to replicate the actual drilling rig and well data for applicable wells. This is done by importing important parameters like length and dimension of flow lines, mud pump capacity, rig choke characteristic, BOP configuration, well trajectory, casing design, drillstring, fluids and formation properties.

The strategy to achieve the set objectives is by training the drilling crews based on the planned drilling program and include scenarios like:

- Drill ahead
- Circulation
- Tripping
- Connection
- Reaming
- Static (no drilling & no flow)
- Well control
- Managed Pressure Drilling
- Complex Drilling Operations
- Cementing and Displacements
- Completions
- Well intervention

In the first phase the drilling simulator is used exclusively for training the drilling crews in the Drilling & Well business units. However, Statoil aims for implementing mandatory simulator training for all drilling crews with a proposed team composition as follows:

- Drilling Supervisor
- Toolpusher
- Driller
- Drilling Superintendent

- Assistant Driller
- Derrickman
- Mudlogger
- Mud engineer
- Cementer
- 2-4 Engineers from the planning teams
- Lead Drilling Engineer from the planning teams

5.1 Case training in simulator

Simulator training courses are divided into classrooms activities (theoretical part) and case training in the drilling simulator (operational part). The theoretical part in the classroom is a preliminary study to give the drill crew the necessary overview and understanding of the operation that is to be carried out in the simulator. Drilling engineers from the applicable license presents information to the crew, such as formation and reservoir description, equipment, risks, special challenges etc. Classroom activities have the intention to bring forth discussions around proposed solutions, challenges and procedures. Through this, the goal is to encourage to knowledge sharing and improve communication within the crew.

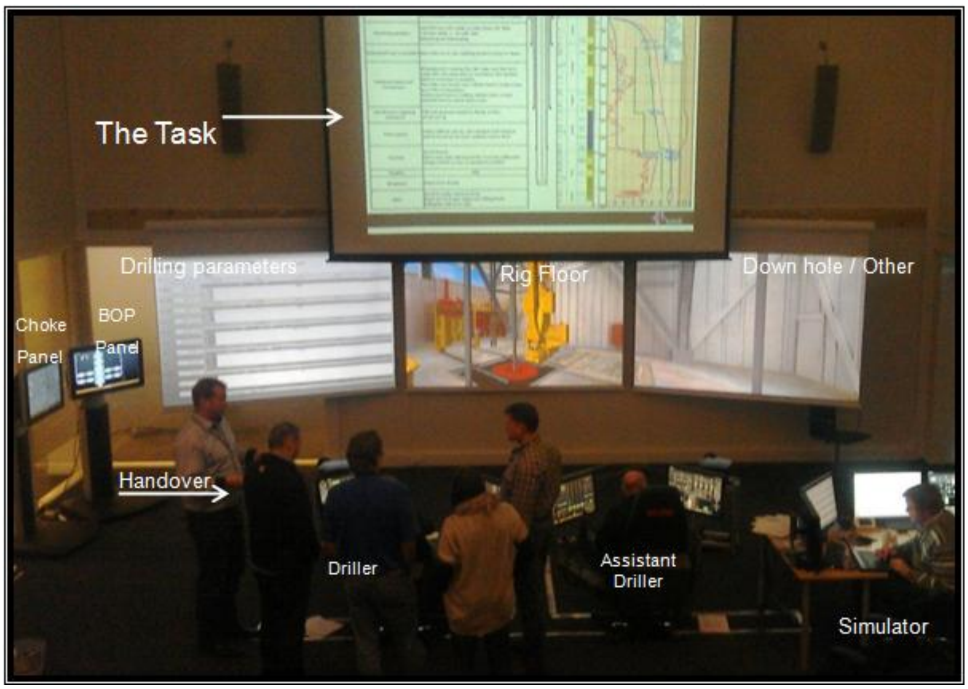


Figure 23: Operational phase in the Full Scale Drilling Simulator.

Operational training in the drilling simulator (see Figure 23) is where the crew executes the given task from classroom session. This gives an increased operational understanding by involving all parts of the drill crew to take their respective roles. The training comprises 2-3 cases with focus on operational procedures, communication as a team in addition to solve problems that the team run into. All operational training is performed in a safe environment which lets the crew discuss problems that may come up offshore in a quiet setting without affecting the real operation.

The drilling simulator is based on 5 modules which are used in order to set-up well scenarios as requested by Statoil:

- Conventional drilling
- Managed Pressure Drilling (MPD)
- Through Tubing Rotary Drilling (TTRD)
- High Pressure – High Temperature (HPHT)
- Extended Reach Drilling (ERD)

There is still work to be done on all modules, but the simulator was in January 2012 ready to run training on the conventional drilling module and HPHT drilling operations.

Statoil practices today one-day training for each crew, but they look into the possibility and utility of conducting training over 2 days. The setup of the agenda throughout a one-day training is shown in Table 3.

Course Agenda for one-day simulator training:

- 08:30 - 09:00 Arrival and Registration
- 09:00 - 09:20 Welcome & Introduction
- 09:20 - 09:30 Introduction of Drilling Simulator
- 09:30 - 10:15 Training on Simulator/Case presentation
    - Training and explanation of buttons and handles
    - Technical information and possible challenges
- 10:15 - 10:30 Coffee
- 10:30 - 12:00 Case 1
    - Drill on from last position. Fingerprints provided.
    - Detect and React on predefined events.
- 12:00 - 12:30 Lunch
- 12:30 - 17:00 Case 2 and 3 (with coffee/snack at 14:30)
    - Drill on from last position. Fingerprints provided.
    - Detect and React on predefined events.
- 17:00 - 18:00 Evaluation and Feedback (All)
    - Evaluation of performance and choices made
    - Risk evaluation, Detection, Communication
    - Technical solutions
    - Fill out evaluation sheet
- 18:00 End of simulator training

Table 3: Course agenda for one day drilling simulator training

The course agenda shown above in Table 3 is for the conventional drilling module. When the Managed Pressure Drilling module is implemented will proactive MPD training require more specialized well engineering design and planning. The rig crews may need some additional guidance to supplement their well control training and they will also need to learn how to safely utilize the tools available today.

5.2 hiDRILL topside module

The source for this section is [17] and [18] unless otherwise is stated in the text.

The simulator combines the generic topside simulator (hiDRILL) with the generic downhole simulator (Intellectus). The topside simulator simulates the drill floor equipment, mud pits, flow lines, standpipe and choke manifolds and BOP operations. The downhole simulator simulates the downhole drilling process and effects related to for example pressure and multi fluid & multi-phase flow, torque/drag, well control & kick simulation etc.

The underlying simulator technology is modular, and thereby allowing for new modules to be implemented at a later stage. This is an important element for the new Coil Tubing module which is to be implemented in august 2012.

5.2.1 Topside modifications

The downhole features of the simulator are the most important features to facilitate advanced drilling training and hence the topside simulator has been implemented in a familiar and simple fashion to be as similar and simple as the equipment used offshore.

The interface between the two simulators is generic and can be extended to allow simulation of other equipment, processes and tools. The topside simulator can be exchanged for another more advanced instance, e.g. replicating the control system, drillfloor and equipment of a specific rig.

5.2.3 Visualization

The 3D visualization of the processes in the wellbore can be extended into areas such as visualizing the usage of tools, volumetric formations, cutting concentration, fluid and gas fronts, visualizing geo-steering and virtual reality visualization of the downhole process. This provides a powerful tool for increased understanding of processes downhole.

The simulator provides great flexibility in configuring the rig equipment-/well-/formation properties. The instructor station application provides means for the instructor to set up scenarios and store them for future use as well as means to execute and monitor said scenarios.

The instructor station uses a familiar Graphics User Interface and facilitates easily adding new equipment or modules to the simulator that can be configured through the instructor application.

Figure 24: Driller and assistant driller`s view over parameters during drilling.

5.2.4 Hardware

The simulator hardware setup focuses on visualization and facilitation of communication between the drilling team members. The driller and assistant driller will not only face a view of the drillfloor, but will also have the option to use two projectors to view 3D or 2D data visualization of the processes in the wellbore. However, since the 2D/3D visualization of processes downhole is not an available option in real operations, this should be considered whether this is appropriate during training.

The hardware configuration can be changed to accommodate varying needs; the projectors can all show different views of the drillfloor, real time drilling parameters and/or for example roadmap. When the MPD module becomes implemented in the simulator will the control station be controlled from the driller`s cabin or placed in the classroom to facilitate communications over intercom or similar means.

5.2.5 Rig equipment

The simulator allows configuring parameters on rig equipment (listed below) in order to emulate rig- or project specific equipment to a high degree with respect to down hole effects:

- Top drive
- Draw works
- Mud pits
- Mud pumps
- Cement pumps
- BOP and rig choke
- MPD choke and flowmeter
- Rotating control device
- Drill string valves
- Flow lines
- Type of installation

5.3 Intellectus - Downhole simulator

The source of this chapter is [18] unless otherwise is stated in the text.

The downhole simulator, Intellectus, contain dynamic models that are able to present all dynamics for all standard drilling and well operations. Intellectus is able to take into account effects like inertia, acceleration and retardation, effects of temperature and pressure changes downhole, well stability and pore pressures. This enables training on important scenarios such as simulation of:

- *Fingerprinting* (flowback effect). It is also possible to train on interpretations of fingerprinting and differentiating between influx and no influx.

- Safe tripping and connection procedures can be trained on by simulations of *Dynamic surge & swab* effects while running pipes and completions.

- *Dynamic kick development*. The training can be based on understanding of gas in wellbore and how this will develop and handled. Thus, training can also comprise detection, reaction and recovery of influx in both oil based and water based drilling fluids.

- Dynamic development of pressure losses in chokes & kill lines during well control.

- Effects of *dynamic temperature changes* on mud properties and cutting transport.

- Realistic feedback on rate of penetration (ROP) and weight on bit (WOB).

Intellectus will in this way enable flexible and realistic approaches to operations performed on the rig offshore, for both fixed platform, jack up and floater. Drilling crews can be trained on the following operations for all the modules listed below:

- Drilling
- Reaming
- RPM effect
- Stripping operations
- Connections
- Ramping rig pumps manual and automatic
- Back pressure pump (MPD)
- Multi fluid operations
- Surge and Swab
- Ballooning
- Well control – handling of kick and loss
- Well Interventions

The listed operations above will be available (where applicable) for conventional drilling, pressurized drilling, Through Tubing Rotary Drilling, High Pressure - High Temperature Drilling and Extended Reach Drilling. The downhole simulator can be extended with additional functionality by adding modules or modifying additional modules by incorporating different algorithms for scenarios.

5.3.1 Well configuration

Well configurations can be performed on the following:

- Well profile/trajectory (straight, S- and J-type)
- Casing and liner (depths, ID/OD, integrity, fracture gradient behind casing/liner, formation fluids, pore gradient)
- Drilling fluids and properties (compressibility, rheology)
- Drillstring and bottom hole assembly
- Geology (formation depths, permeability, kick/loss zones, faults, collapse, temperature effects, minimum horizontal stress, formation pressures and fracture gradients, formation fluids).

5.4 Dynamic downhole models

The dynamic downhole simulator consists of an advanced transient integrated hydraulics/thermal model and a dynamic torque/drag model for calculations of mechanical forces in the drill string and all hydraulics generated by temperature and fluid flow. The flow model is a dynamic thermo-hydraulic model characterized as a general, flexible two-phase model that is adapted to the actual needs and requirements in the Drilling Simulator Project. The main objective of the Torque & Drag Model is to calculate the mechanical and hydraulic forces acting on the drill string. Knowledge of string forces and string torque is essential for monitoring and diagnosis of a drilling process.

5.4.1 Flow model

The dynamic flow model developed by SINTEF is here described in a limited form to cover the version used in the Drilling Simulator. The functional design of the flow model considers four different aspects:

- Geometry
- Numerical features
- Fluids
- Formation and reservoir

The challenge in making a simulator with advanced flow models have been to establish a simulator kernel that is able to include all the important physical parameters, important events, compute realistic results and compute the results at a sufficient speed to meet the real time requirements [19]. The underlying mathematical model describing the advanced flow model consists of governing equations comprising mass conservation of each fluid component and conservation of the total momentum for the system. The numerical feature calculates the flow path in fragments, where each fragment consists of a number of grid cells that are linked together. The fragments are connected such that it represents the actual physical system to be modeled in such a way that requirements on calculation speed and accuracy are met.

The governing equations are based on the following assumptions [19]:

- All variables depend on only one spatial dimension, i.e. the flow along the flow line.
- Temperature is known and depends only on the spatial coordinate.
- Gas can be dissolved in oil but not in water.
- A fluid is composed of up to five different components and may include: Drilling mud; Formation gas; Formation oil; Formation water and Formation cuttings.

The solution procedure can be divided into local- and global procedure. The local solution procedure is used for updating the solution in one grid box based on the setup shown below in Figure 25. An important element for this setup is the flexibility contained with the non-uniform spacing of grid boundaries. Smaller grid boxes around the bottom hole assembly (BHA) will ensure more accurate flow modeling throughout the well. Densities are approximated at box centers while pressure and velocities are approximated at grid box boundaries. The boundaries are denoted with a terminology as follows [19]:

- Upstream boundary is referred to as the grid box boundary where flow is entering the grid.
- Downstream boundary is the boundary where flow is leaving the box.

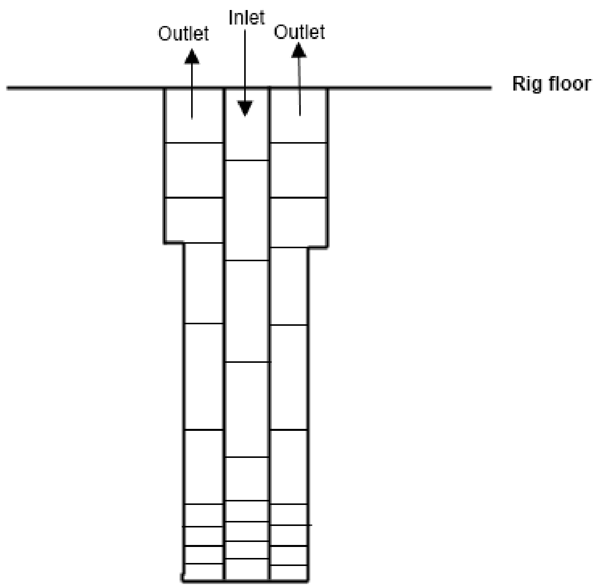


Figure 25: Discretization of the flow network.

The typical fluid composition within a box is illustrated in Figure 26. The fluid components are drilling fluid, formation fluid, cuttings and free gas. How the fluid components are transported depends on the problem modeled. If free gas may be present it is assumed that drilling fluid, formation fluid and cuttings are all grouped together in one phase with a common velocity, while gas is representing the second with a different velocity. Generally, gas and liquid flows with different phase velocities in pipe flow are defined as:

$$u_L = \frac{q_L}{A_L}$$

Where,

u_L = phase velocity
q_L = flow rate liquid
A_L = cross sectional area of liquid

$$u_G = \frac{q_G}{A_G}$$

Where,

u_G = phase velocity
q_G = flow rate gas
A_G = cross sectional area of gas

Different phase velocities can also occur without the presence of gas. Then drilling- and formation fluid are grouped into one phase and cuttings represents the other phase.

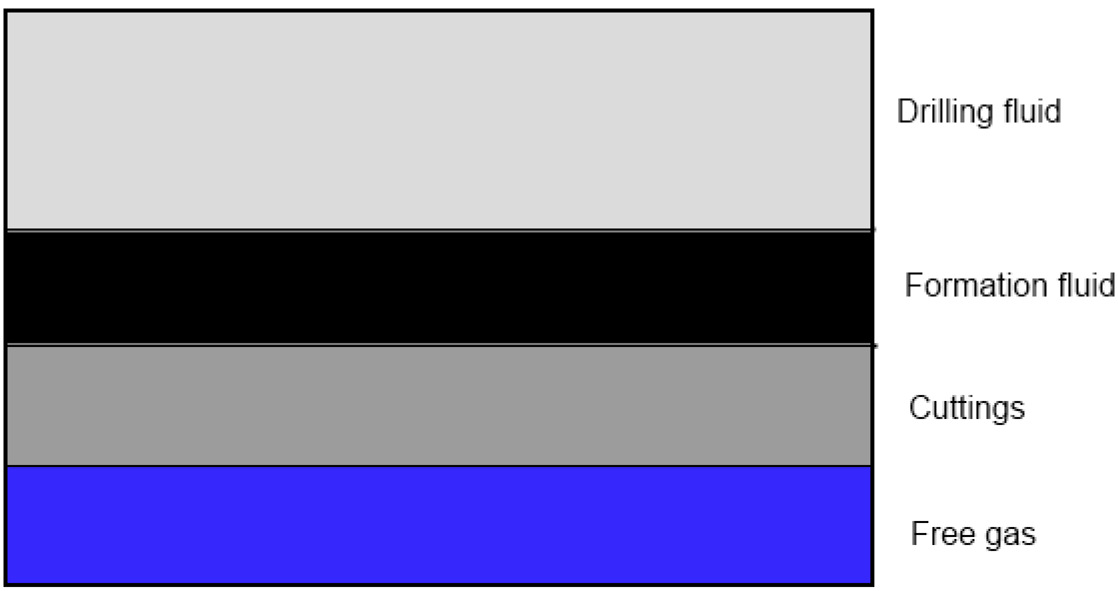


Figure 26: Fluid components in a grid box.

Due to possible discontinuities at grid box boundaries, pressure and velocities are assigned two values for each grid box. As shown in Figure 27, grid box nr i is denoted p_{i-} for pressure at upstream boundary and p_{i+} at downstream boundary. The same indices are used for drill mud velocity v_1 and formation fluid velocity v_f.

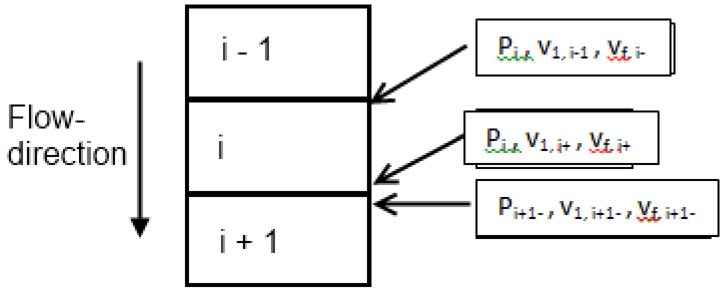


Figure 27: A section of the grid of computation.

5.4.1.1 Fluids

In drilling fluids, the flow behavior of the fluid must be described using rheological models and equations before the hydraulic equations can be applied [20]. The physical properties of a drilling fluid, density and rheological properties contribute to several important aspects for successfully drilling a well. Examples of the function of a drilling fluid are:

- Pressure control to control influx of formation fluid into wellbore
- Provide wellbore stability through pressured or mechanically stressed zones
- Suspend cuttings and weight material during static periods
- Remove cuttings from the well
- Provide energy to optimize rate of penetration (ROP)

The current real time version of the model is limited to the flow of a train of non-mixing fluids, as well as drill cuttings which may have slip. Slip occurs when gas (u_G) and liquid (u_L), or fluids and cuttings flow have different velocities. The relative phase velocity (u_S) or the slip velocity is defined by

$$u_S = |u_G - u_L| \quad \text{(Eq. 5)}$$

This shows that the phases may move slower than or even opposite of the fluid flow. Fluids can have different properties (density, rheology, thermal properties) dependent on its positioning along the flow trajectory.

A fluid is represented by a hierarchy of fluids and fluid components. The following example shows a traditional liquid drilling mud:

<table>
<tr><td colspan="7">Current mud</td></tr>
<tr><td colspan="6">Original mud</td><td rowspan="4">Added weight materials</td></tr>
<tr><td colspan="4">Brine</td><td rowspan="2">Oil</td><td rowspan="2">Weight material</td></tr>
<tr><td>…</td><td>Salt 1</td><td>Salt 2</td><td>Water</td></tr>
</table>

Table 4: Traditional liquid drilling mud.

5.4.1.2 PVT properties

The way hydraulic model compute the evolution of the state of the well, the pressure computations and the heat/thermal computations are offset from each other. They are not computed simultaneously, which simplifies the computation. Pressure, volume (internal energy) and temperature (PVT) properties describe the state of matter under a given set of physical conditions. Density calculations on fluids can be performed by applying PVT modeling based on one of the following options:

- Experimental results from laboratory, where density vs. pressure and temperature are measured and combined with rig measurements of standard conditions density.
- A compositional model treating water/brine, oil and solid phases separately. Water/brine and oil densities are then tested against different pressure and temperature which yields results that can be used to perform calculations based on laboratory data or published correlations. Solid material is considered incompressible.

5.4.1.3 Rheology and frictional pressure loss

Rheology is the study of how matter deforms and flows. It is primarily concerned with the relationship of shear stress and shear rate and the impact these have on flow characteristics inside tubular and annular spaces. In this downhole model, standard Fann rheology data is input into the model. Data can be given at different combinations of pressure and temperature, in which case the model will interpolate to actual conditions at each position along the flow trajectory. Pressure and temperature dependent rheology data from a laboratory can be combined with on site measurements at atmospheric pressure to improve accuracy.

Herschel-Bulkley and Robertson-Stiff have developed “three-parameter rheology models” and they are fitted to all rheology data and used for frictional pressure loss calculations. Herschel-Bulkley`s model is described mathematically as follows:

$$\tau = \tau_0 + k(\gamma)^n \qquad \text{(Eq. 6)}$$

Where,
τ = shear stress
τ_0 = yield stress

k = consistency
γ = shear rate
n = power law exponent

These models are fitted to all rheology data and used for frictional pressure loss calculations. Normally are drilling fluids very accurately represented by these models by a yield stress test (Fann). The yield stress is normally taken as the 3 rpm reading, with the *n* and *k* values then calculated from the 300 or 600 rpm values or graphically [21].

5.4.2 Torque and Drag model

The implemented torque and drag model uses a soft-string-model which is based on the assumption that the string is soft between each segment throughout the well. One segment is equal to the length of each stand, which is typically 9 – 13 m. The model will calculate forces acting on each segment similar to how the string will bend depending on the well`s coordinates. Thus, it will be important to make regular comparisons of already drilled wells and/or real-time measurements prior to simulator training in order to calibrate the models.

5.4.2.1 Drag

Generally, drag force is described as the force difference between free rotating weight and the force required to move the string up or down the wellbore. Thus, drag can be seen as the excess load compared to rotating drillstring weight, which can be positive when pulling the drillstring or negative when sliding the sting into the well.

A characteristic of a straight wellbore is that pipe tension is not contributing to the normal pipe force, and hence affecting friction. For straight inclined wellbore sections without pipe rotation will friction be weight-dominated as only the normal weight component gives friction. The top force F_2 of an inclined pipe is given by [22]:

$$F_2 = F_1 + \beta \Delta L w \left(\cos\alpha \pm \mu \sin\alpha\right)$$

Where,

"+" and "-" sign means hosting and lowering respectively of the pipe
F1 = force in string
β = buoyancy factor
ΔL = pipe length
w = unit pipe weight
α = wellbore inclination
μ = coefficient of friction

5.4.2.2 Torque

Torque or "moment of force" is generally a force multiplied with a lever arm. Generally is the main contributor to increased surface torque due to the friction arising between the wellbore and the drill string. The wellbore profile with the actual doglegs and tortuosity will determine the intensity of friction that will arise. As a result will the sum of friction forces along the drill string be the resulting torque required to rotate the string at sufficient rotation speed. Mathematically can torque be formulated as shown in Figure 28:

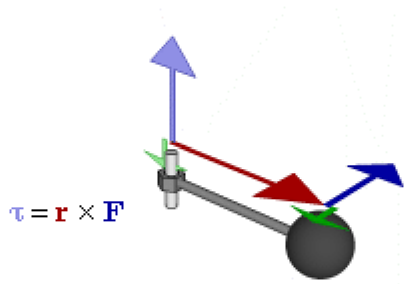


Figure 28: Mathematically expression for torque [23].

Where,

τ = magnitude of torque
r = length of lever arm
F = magnitude of force

When rotational force is applied to the string at rig floor, will friction generated by drillstring contact with the wellbore reduce the surface torque transmitted to the bit. Hence, performing analysis and/or estimation of friction forces when planning a well will be very useful in order to avoid pipe failure.

The torque for a straight inclined wellbore section without axial pipe motion can be defined as the normal weight component multiplied by the coefficient of friction and the pipe tool joint radius [22]:

$$\tau = \mu r \beta w \Delta L \sin \alpha$$

Where,
β = buoyancy factor
ΔL = pipe length
w = unit pipe weight
α = wellbore inclination
μ = coefficient of friction
r = pipe radius

5.4.3 Implemented torque and drag model

The main objective of the torque and drag model as used in eDrilling, is to calculate the mechanical and hydraulic forces acting on the drill string, i.e. torque, axial tension and pressure in real time.

Torque and drag modeling is an essential part of the planning and execution of wellbore operations using a workstring. This type of modeling does not only provide information about the ability to transmit force and torque along the string to the drill bit, but it is also necessary for calculation of the stress state of the string, and thus for string integrity assessment and monitoring.

The model can perform calculations on the following types [24]:

- Calculate weight on bit (WOB) with input of hook load or vice versa.
- Calculate bit torque with input of surface torque or vice versa.
- Back-calculation of friction factor with input of measured surface and bottom hole weights or torques.
- Bit depth correction due to string elastic.
- Initial calibration of rig specific parameters, such as model parameters for force/torque transfer from the top drive system to the string.

6. Description of different simulator modules

In this section you will find an overview over planned modules and operations that are/will be implemented in the simulator. The source for this chapter is confidential contract documents for Statoil unless otherwise is stated in the text.

6.1 Conventional Drilling

The simulator is capable to simulate all normal sub-operations during drilling, such as drill ahead, tripping, statically with and without circulation, off bottom and making connections. During these sub-operations the downhole model will compute the response of the operations and changes in operational parameters (pump rate, WOB, ROP, mud properties, tripping velocity etc.) on the well pressure profile (ESD & ECD). For all the sub-operations listed below, the downhole model has dynamically simulated well pressures:

- RPM-effects

- Connections: The downhole model supports ramping the rig pumps both manually and automatic. This is supported both with and without a back pressure pump (MPD mode).

- Tripping (surge and swab): The downhole model supports tripping with a realistic response on hook load.

- **Bring the well to overbalance:** The downhole model supports setting balanced mud pill, displacement of balanced mud pill and bottom kill.

- **Cementing:** The downhole model fully supports this.

- **Well control:** The two-phase variant of the Contractor`s dynamic flow model can be used to represent the well, both with influx and losses.

- **Pipe failure:** The downhole model supports the following pipe failures:

  - *Blocking* of drillstring/nozzles

  - Modeling of sudden change in flow path due to *twist off*. Supervisor can determine when and where there is twist-off. The well model will immediately change flow path and let all flow go out at given twist-off point. Torque and hook load will drop.

  - Modeling of sudden change in flow path due to drillpipe *washout*. Well model will gradually change flow path by letting more and more flow go out at a given depth. Linear increase in flow through hole/crack over a given time.

  - Implementing bleeding off pressure at standpipe (and filling of new pipe) due to *non-return valve (NRV) failure*.

- Leakage in common well barrier element: Pressure dependent reduction of flow through chokes, with input of duration and how much flow is reduced.

6.2 Managed Pressure Drilling (MPD)

The drilling simulator will be set up with the same downhole model that has been extensively used in connections with all Statoil UBD and MPD operations so far. The model has been proven to be very stable and gives good results [25]. A realistic choke response is calculated by the well model by implementing a standard dynamic choke response. For all the sub-operations listed below, the downhole model will dynamically simulate well pressures and be used for automatic choke control:

- Initiation of MPD-modus: The downhole model fully supports the transition from conventional drilling to MPD. A link of chokes and pumps will be implemented with a realistic response. This includes opening and closing a number of valves to direct flow through the MPD chokes, starting back-pressure pump (BPP), and gradually build pressure by closing chokes.

- **Transition from MPD to well control:** The downhole model will fully support the transition from MPD to well control with a realistic response of chokes and pumps. When detecting a small gain (volume increase and/or differential flow between given thresholds), one of the drill crew members will need to re-route flow to have return through degasser, but still with pressure controlled by MPD chokes. The well model will calculate the small changes in pressure loss through surface lines due to re-routing flow. In addition will the gas fraction be calculated vs. time through the MPD choke with response influenced by gas. When detecting a larger gain, the MPD system will be by-passed by re-routing flow to go through choke line and rig chokes, and closing annular rams (i.e. revert to standard well control handling). Response of rig choke will replace response of MPD choke. Contrary, the transition from well control to MPD is also fully supported by reversing the operation. Choke blocking can also be triggered by supervisor or set to occur at a random time, and will be included in the well model by tweaking the choke response. Choke pressure will increase somewhat and become unstable. The typically response from a trainee is to close the blocked choke (or a valve isolating it) and at the same time start opening the other choke. The well model will then calculate the response of both chokes over a short time span, one tweaked and one not.

- **Pipe failure:** The downhole model supports the following pipe failures:

- *Blocking* of drillstring/nozzles

- Modeling of sudden change in flow path due to *twist off*. Supervisor can determine when and where there is twist-off. The well model will immediately change flow path and let all flow go out at given twist-off point. Torque and hook load will drop.

- Modeling of sudden change in flow path due to drillpipe *washout*. Well model will gradually change flow path by letting more and more flow go out at a given depth. Linear increase in flow through hole/crack over a given time.

- Implementing bleeding off pressure at standpipe (and filling of new pipe) due to *non-return valve (NRV) failure*.

- Loss of rig power: Sudden loss of rig pump and back pressure pump will be fully implemented. It is assumed that chokes are remotely operated, i.e. the choke control system does not lose power. Rig pump or both pumps will in this case shut down very quickly, and chokes must be closed quickly to keep as much pressure as possible. Due to the quick change in flow choke, oscillations will be seen and must be handled. Choke must be closed both to compensate for reduced flow through the choke, but also to compensate for loss of friction in the annulus, i.e. choke pressure target will increase by 20-30 bar typically.

6.3 Well control

The downhole model has been used to handle well control cases, and models influx scenarios including all phases of a well control operation.

Drilling and well personnel will be trained on detection, reaction and recovery of the following operations:

- Stripping operations:
  - Surge and swap effects
  - Stage up rig pumps manually and automatic
- Influx, losses and/or simultaneous influx and loss
- Surface blockage (choke and flow line)
- Pipe failures:
  - Blocked drill string/nozzle
  - Pipe twist-off
  - Drill pipe wash out
- Loss of rig power
- Problem diagnostic including training on drillers first action
- Gas in riser
- Shallow gas blow out

Well intervention personnel can be trained on various leak scenarios, where they can be trained on handling leakages below safety head, between safety head and BOP and leak above BOP.

6.4 Down hole understanding and Extended Reach Drilling (ERD) wells

The well model will be capable of giving a response that mimic partly blocking of the wellbore due to pack-off/bed formation/pulling out of uncleaned hole or collapse of wellbore. In addition to this, simulator training is planned to be performed on the following cases to give better understanding of down hole processes in conventional wells and ERD wells:

- Losses (seepage, total loss)
- Provoked losses due to surge/swab effects
- Connections
- Handling of pack-offs

- Tripping operations
- Drilling in stringer
- Hole cleaning

6.5 Through Tubing Rotary Drilling (TTRD)

The well model will support TTRD operations, where the training is planned to concern scenarios that can cause well control incidents. Losses, kick, hole cleaning, connection and provoking the formation to initiate kick/losses will here be trained on in the same way as for other operations. The risk of using TTRD technology is the increased wear in casing/production casing in motherbore, where excessive wear can cause influx situations or losses from/to exposed formations higher up than the kick-off point. Training will also concern dry tripping, where heavy pill/slug is placed in drillstring to be able to pull dry out of the well.

7. Comparison of simulator calculations

Statoil's in-house planning tools for drilling and well operations are Drillbench and Wellplan. In this chapter will simulated ECD values from both simulation tools, Drillbench and drilling simulator (Intellectus), be compared with each other. This comparison is performed as a check for consistent results between the two simulation tools. Simulated ECD values to be compared are based on three different intervals from a well located in one of Statoil`s field in the North Sea. The well has been assigned the fictitious name "Well A", due to confidentiality. As the drilling operation on Well A has been finished, there are available real-time data from the operation that makes it possible to compare the simulated ECD values against the value that was current during the operation. This is the only well that has finished drilling operation with available real-time data. The comparison of ECD values between real-time operation and simulated result is performed to confirm the simulators reliability and realistic behavior.

7.1 Planning tool

Drillbench© is a simulation tool developed and marketed by the Scanpower Petroleum Technology (SPT) Group. The SPT group is a leader in dynamic modeling for the oil and gas industry, offering software and consulting services within multiphase flow and reservoir engineering [26]. Drillbench consists of the modules illustrated in Figure 29.

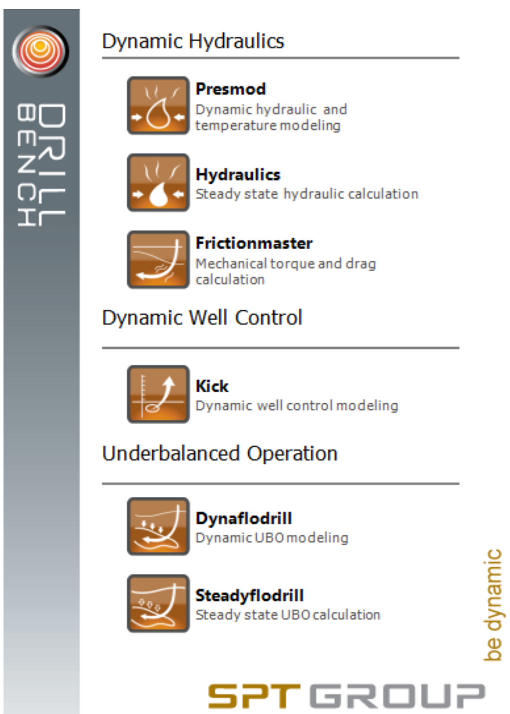


Figure 29: Overview of implemented modules in Drillbench

For this case study will comparison of simulations be performed with Drillbench Presmod module which is a tool used to evaluate how operational conditions and critical fluid properties influence pressure (ECD) and temperature conditions in the well. Drillbench Presmod takes into account dynamic temperature calculations in the hydraulic model. As a planning tool will Presmod enable monitoring of processes that occur, thus allowing the drilling engineer to supervise that the well conditions will meet the design requirements throughout the operations [26].

Description of SINTEF`s downhole simulator, Intellectus, can be found in section 5.3.

Generally is input data for both Drillbench and SNITEF`s simulation model based on a "Standard Input Data Sheet" excel file where surveys, wellbore geometry, formation layers, expected pore- and fracture pressure, drillstring setup (incl. BHA), fluids, rig data and geological layers are all added to the input file which then performs the necessary calculations. Snapshots of the input file are illustrated below in Figure 30, Figure 31, Figure 32 and Figure 33.

Total Depth (RKB) mMD	Vertical Depth (RKB) mTVD	Min PP (sg)	Exp. PP (sg)	Max PP (sg)	Min Fracture (sg)	Exp. Fracture (sg)	Max Fracture (sg)	Min Collapse (sg)	Exp. Collapse (sg)	Max Collapse (sg)	LOT (sg)	FIT (sg)
163,52	163,52		0,690			0,73						
200,05	200,05		0,750									
250,16	250,16		0,804									
300,26	300,26		0,841			1,231						
350,36	350,36		0,868									
400,47	400,45		0,888									
403,69	403,67					1,383						
450,58	450,49		0,903									
500,73	500,47		0,916									
501,59	501,33					1,471						
600,29	599,24		0,935									
700,52	698,00		0,949									
703,68	701,12					1,575						
800,66	796,62		0,959									
803,03	798,96					1,607						
899,93	894,38		0,966									
1 000,28	993,21		0,973									
1 002,21	995,11					1,655						

Figure 30: Snapshot of formation data input.

FLUID 1		Fluid name:	XP07		Density (sg):		2,02		Oil/Water ratio:		80/20	
		Active rheology (Fann 35 measured on location) (lbf/100ft^2)::										
Density oil (sg):	0,74	Temperature (C)	600	300	200	100	60	30	6	3	PV	YP
Density water (sg):	1,03	50	41	23	17	12	9	7	4	4	18	4
Density HG soldis (sg):	4,2										0	0
Density Drill solids (sg):											0	0
Retorte oil (%):											0	0
Retorte water (%):											0	0
Retorte solids (%):											0	0

Fann 70 (lbf/100ft^2)	Pressure (bar)	Temperature (C)	600	300	200	100	60	30	6	3	PV	YP
	0	50	41	23	17	12	9	7	4	4	18	4
	100	50	45	25	20	13	10	7	4	4	20	5
	200	50	52	29	22	14	11	8	5	4	23	7
	300	100	32	17	14	10	7	6	3	3	14	3
	450	100	36	20	15	11	8	6	4	3	17	3
	600	100	41	22	17	11	9	7	4	4	19	3
	750	160	28	15	11	8	6	5	3	2	13	2
	820	160	30	16	12	9	7	5	3	3	13	3
	950	160	33	18	14	9	7	5	3	3	15	3
											0	0
											0	0
											0	0
											0	0

PVT Fluid phase (Specific gravity)	Pressure	Temperature	(Celcius)	(Celcius)	(Celcius)	(Celcius)	(Celcius)	(Celcius)	(Celcius)	(Celcius)	(Celcius)	(Celcius)
	(Bar)		21,7	66,1	121	160						
	34,5	=>	0,7644	0,7319	0,6965	0,6679						
	172,5	=>	0,7731	0,7425	0,7109	0,6858						
	344,8	=>	0,7828	0,7542	0,7257	0,7031						
	517,2	=>	0,7914	0,7643	0,7381	0,7169						
	689,6	=>	0,7994	0,7735	0,7488	0,7290						
		=>										

Figure 31: Snapshot of fluid data input.

Rig name		Well Name
West Epsilon		A-5

Trip Tank Capacity (ltr)	Pump output TT pump (ltr)	TDS drilling torque max (lb-ft)	BOP position ref. RKB (m)	Block weight (ton)
10920		56700		50

Rig Pumps Pump #	Capacity (100%) (ltr/strk)	Efficiency (%)	Max SPM	Max RPM	Actual PO (ltr/strk)
Pump 1 6 1/2" liner	23,74	97	100		23,03
Pump 2 6 1/2" liner	23,74	97	100		23,03
Pump 3 6 1/2" liner	23,74	97	100		23,03
Cement pump					0,00

Surface lines	ID (in)	Length (m)	Vertical position of start (m)	Vertical position of top (m)	Vertical position of end (m)	COMMENT
Surface line (kelly, standpipe)						(From mud pump to RKB)
Kill line:	3	26				
Choke line:	3	26				
Degasser line:						
Vent line:						
Return line:						(From flowline to mud pit)

Sensor positions Sensor type	Line	Distance from Start of line (m)	Vertical position (m)	Rig choke type: Choke opening (%)	Choke type CV value	Rig choke type: Choke opening (%)
				0		0
				10		10

Figure 32: Snapshot of Rig data input.

Measured Depth (m)	Inclination (deg)	Azimuth (deg)	TVD (m)	Northing (m)	Easting (m)
163,00	0,00	0,00	163,00	-13,19	3,03
180,00	0,00	0,00	180,00	-13,19	3,03
210,00	0,00	0,00	210,00	-13,19	3,03
240,00	0,00	0,00	240,00	-13,19	3,03
270,00	0,00	0,00	270,00	-13,19	3,03
300,00	0,00	0,00	300,00	-13,19	3,03
330,00	0,00	0,00	330,00	-13,19	3,03
335,00	0,00	0,00	335,00	-13,19	3,03
360,00	0,83	259,32	360,00	-13,22	2,86
390,00	1,83	259,32	389,99	-13,35	2,17
420,00	2,83	259,32	419,97	-13,57	0,97
450,00	3,83	259,32	449,91	-13,90	-0,74
480,00	4,83	259,32	479,83	-14,32	-2,97
510,00	5,83	259,32	509,70	-14,83	-5,71
540,00	6,83	259,32	539,51	-15,45	-8,96
570,00	7,83	259,32	569,27	-16,16	-12,73
600,00	8,83	259,32	598,95	-16,96	-17,00
630,00	9,83	259,32	628,55	-17,87	-21,78
635,00	10,00	259,32	633,48	-18,02	-22,63
660,00	10,00	259,32	658,10	-18,83	-26,89

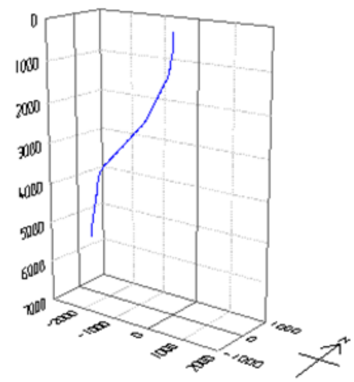


Figure 33: Snapshot of survey data input.

7.2 Description of case

The simulated results are all performed on Well A from a Statoil operated field located in the North Sea. The field is under development and according to plan for Plan of Development (POD) is the field aiming for production start within first quarter in 2014. Hence, Well A is characterized as a high pressure – high temperature (HPHT) field which causes extra challenges as described in section 4.5.1. The first reservoir section is found from 4200 MD with a reservoir pressure varying from 780 - 820 bars. Due to this nature will Statoil have to pre-drill all of the 7 planned wells before production can start in order to avoid pressure depletion with related problems.

The applicable licensee performed training on the following three different cases during simulator training:

1. Drilling 12 ¼" section at 4603 mMD, with a planned TD at 4625 mMD. A gas kick was taken at 4607,25 mMD with a high influx rate.
2. Drilling 8 ½" section at 4621 mMD, with a planned TD at 4625 mMD. Low influx was observed during connection due to swabbing.
3. Drilling 8 ½" section from 5547 – 5552 mMD, when a fault encountered. A loss situation occurred, which eventually resulted in an underground blow-out.

The simulated results seen in the drilling simulator are compared with the results calculated with Statoil`s in-house planning tool, Drillbench. Simulations were performed with the same setup and input data as the drilling simulator. Comparison between the simulated results has been made to verify that the results are consistent and coincide.

The geological input data for all simulations are based on geological surveys and stored data that is applicable for this well. Drilling parameters are similar to the pre-planned parameters found in the mentioned "Standard Input Data Sheet" made by the responsible drilling engineer.

The simulated results from Drillbench and drilling simulator are derived from the only comparable intervals, 4603 - 4607 mMD and 4621 – 4625 mMD. Unfortunately was case number 3 from simulator training not applicable for comparison with real-time data. This is due to operational changes that make comparison unreasonable.

7.3 Comparison of simulated results and real-time data

In advance of every simulator training have Statoil's project team conducted in-house simulations with Drillbench and Wellplan of the proposed cases each licensee is to be trained on. Statoil`s simulated results are then compared with corresponding results from the drilling simulator, as a quality check for both parties and thus ensures the results to be in accordance with expected results. For this comparison have Drillbench adapted the same setup of input data that was applicable during simulator training. This was done in order to ensure a similar comparison basis for the applicable intervals. Since both simulation tools are based on two different simulation models, was a comparison of simulated results set up as a test to confirm that they both are aligned and returns coincide values.

The comparison of real-time ECD value and simulated ECD was intended to illustrate the values that were applicable during training compared to the values seen during operation. Hence, the comparison basis is not representative for direct comparison since different drilling parameters have been used for simulator training and real-time operation. Table 5 and table 6 illustrate the applicable drilling parameters for the three selected depths.

As the real-time drilling operation of Well A was changed compared to performed simulator training, is the interval from 5100 – 5200 selected for a direct comparison of real-time and simulated ECD values. Drillbench is here set up with the same drilling parameters as seen during real-time operation in order to test the accuracy of simulation tools.

For the applicable comparison of simulated values were the drilling operation conducted with a 12 ¼" PDC drill bit from 4603 - 4607 mMD and a 8 ½" PDC drill bit from 4621 – 4625 mMD. For all comparable sections that are relevant in this context was the real-time drilling operation carried out with a 8 ½" PDC drill bit.

The input parameters for performed simulations are as follows:

	Parameters for simulation program			
Bit depth	Pump rate	MW	RPM	ROP
4607	1412	1,60	162	7,2
4621	1394	2	131	4,3
4625	1417	2	131	19,3

Table 5: Input parameters for simulation program.

The real-time parameters from drilling operation are as follows:

	Real-time parameters			
Bit depth	Pump rate	MW	RPM	ROP
4607	1413	2	163	4,8
4621	1409	2	172	1,7
4625	1401	2	175	0,7

Table 6: Real-time drilling parameters for Well A.

As described in chapter 2, is Equivalent Circulating Density (ECD) defined as the pressure at any given depth expressed in the terms of mud density at a given true vertical depth. During drilling operation will ECD fluctuation generally be related to mud pumps being tuned up and down, hence hole cleaning is also a vital factor affecting the ECD. ECD values are the basis for comparison in this case study.

Figure 34 and Figure 35 shows the simulated results from Drillbench and drilling simulator respectively. As illustrated are the simulated values from both simulation tools in line and corresponds to each other, with a deviation from 0,005 – 0,007 sg. The mentioned deviation shows that both simulation tools are consistent and coincide. Since each case that is applicable for simulator training is prepared and controlled by both parties, shows the result that both simulation models return virtually identical values when the input data is the same. This result is important for Statoil`s license holders as the performed training is according to their operational plan for drilling operation.

ECD at bit depth [g/cm3]	
Bit depth	Drilling simulator
4607	1,632
4621	2,048
4625	2,050

Table 7: ECD at bit depth from Drilling Simulator.

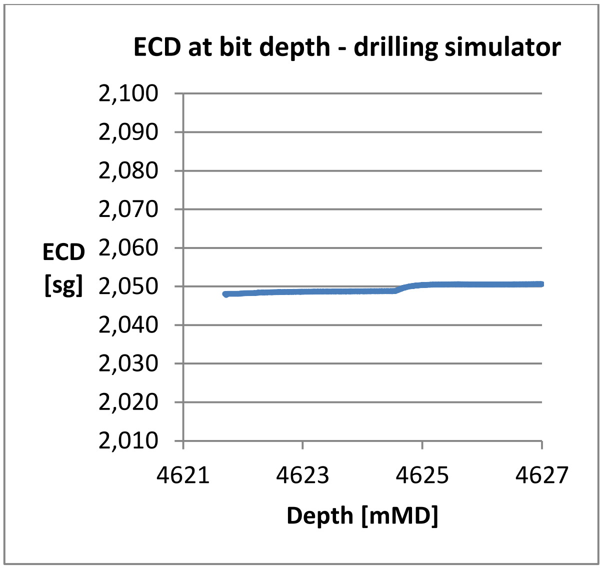


Figure 34: Plot of simulated ECD value from drilling simulator in the interval from 4622 – 4626 mMD.

ECD at bit depth [g/cm3]	
Bit depth	Drillbench
4607	1,638
4621	2,055
4625	2,055

Table 8: ECD at bit depth from Drillbench.

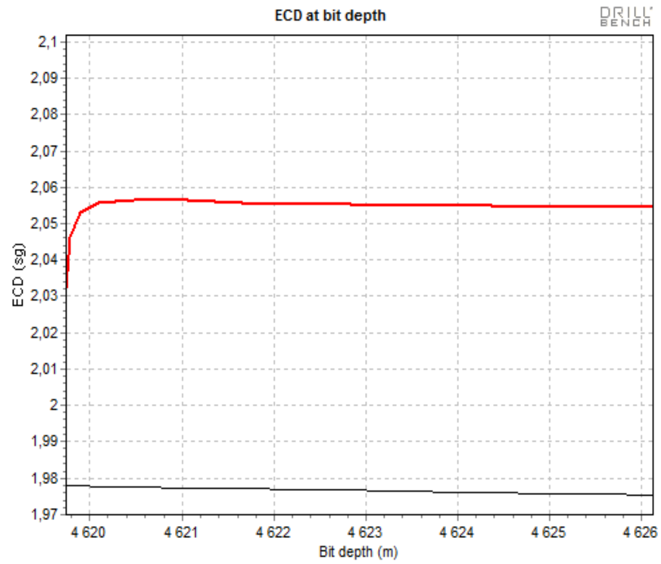


Figure 35: Plot of simulated ECD value from Drillbench in the interval from 4620 – 4626 mMD.

Real-time data shows a higher ECD value compared to simulations, see Figure 36 and Table 9. The discrepancy in ECD value can be explained partly due to difference in drilling parameters and partly by various rheology properties of the drilling fluid. Other factors that can describe the increased value of ECD seen real-time could be related to an increase in frictional pressure and/or due to poor hole cleaning. The originally planned drilling fluid was applied at the start of the drilling operation. Hence, the selected fluid was not optimal as sag problem encountered. Due to this were the rheological properties changed to be more adapted and suitable for the applicable environment seen downhole. Changes in rheology properties will cause changes in ECD values seen downhole. The effect of sources of error is out of scope for this thesis and will thus not be further explored. As real-time operations continuously adapt drilling parameters to operated environment in order to optimize efficiency and safety, will a simulation program perform simulations according to given input data. This fact is seen for this drilling operation, as both RPM and ROP parameters deviates from the pre-planned parameters used for simulator training.

ECD at bit depth [g/cm3]	
Bit depth	Real-time data
4607	N/A
4621	2,131
4625	2,128

Table 9: ECD at bit depth from real time data.

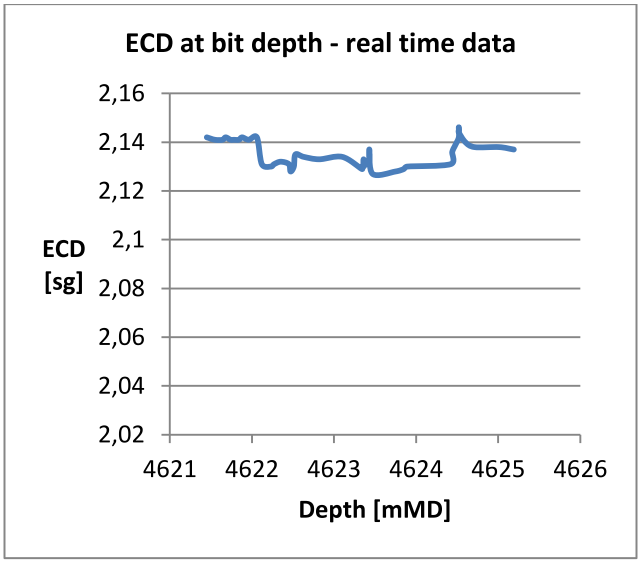


Figure 36: Plot of ECD at bit depth based on real time data in the interval 4621 – 4626 mMD.

Since all applicable intervals for comparison with real-time data was not optimal to direct comparison with the expectation of coincide results, was it desirable to verify Drillbench as a planning tool. In order to evaluate the implemented downhole model in the drilling simulator as a realistic simulator tool, was Drillbench set up with the same input data and parameters as seen during real-time operation. Since the simulated results from comparison above are compliant and consistent, will consistent results between Drillbench and real-time data also be a verification of SINTEF`s downhole model as a consequence. This is justified by the fact that Statoil and SINTEF prepares each training session in collaboration and calibrate the results against each other, which ensures consistent results.

Figure 37 shows the simulated ECD value performed with Drillbench for drilling the interval 5100-5200 mMD. The real-time data from a captured interval is shown in Figure 38, and the result shows that simulated values of ECD are to be recognized in the field.

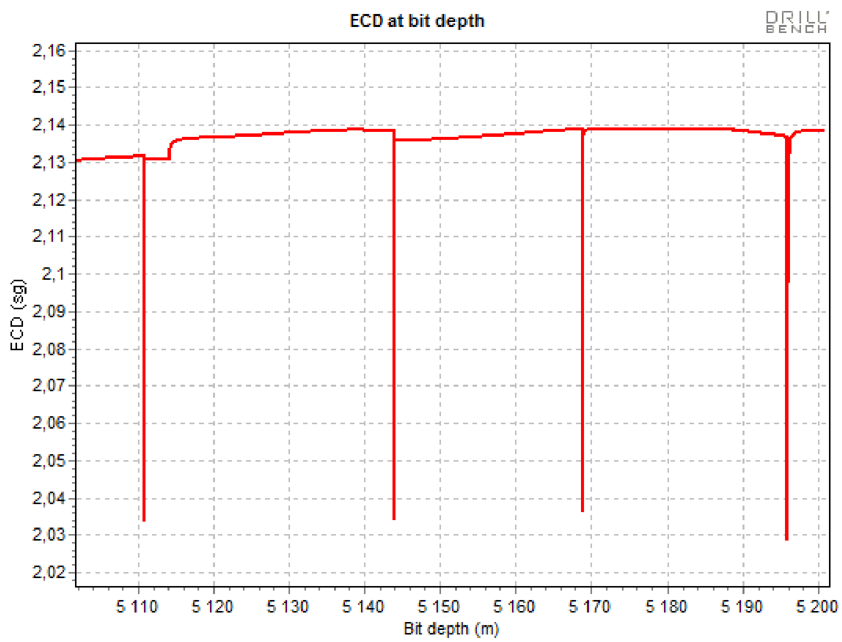


Figure 37: Simulated ECD value from Well A, 5100 - 5200 mMD.

By comparing simulated ECD and ESD values at bit depth with real-time ECD value for the selected intervall the following results arise:

	ECD at bit depth during drilling	
Depth	ECD Drillbench	ECD Real-time
5110	2,130	2,130
5120	2,137	2,130
5130	2,139	2,140

Table 10: ECD values during drilling operation.

ESD at bit depth during connection				
Depth	ESD Drillbench		Depth	ESD real-time
5110	2,035		5113	1,997
5144	2,035		5142	1,994

Table 11: ESD at bit depth during connection.

This verification confirms that both Drillbench and SINTEF`s simulation tool simulates operational parameters that are aligned with parameters seen offshore. Hence, this result shows that simulation software as a planning tool of drilling operations are consistent and valuable for engineers during planning phase. This result strengthen the view of having a realistic and credible simulator tool that can raise competence level throughout drilling & well organization.

Statoil has a great opportunity through simulator training in a full scale drilling simulator to ensure more efficient and safe operations in an environment that is almost as realistic as possible when it comes to training outside the field.

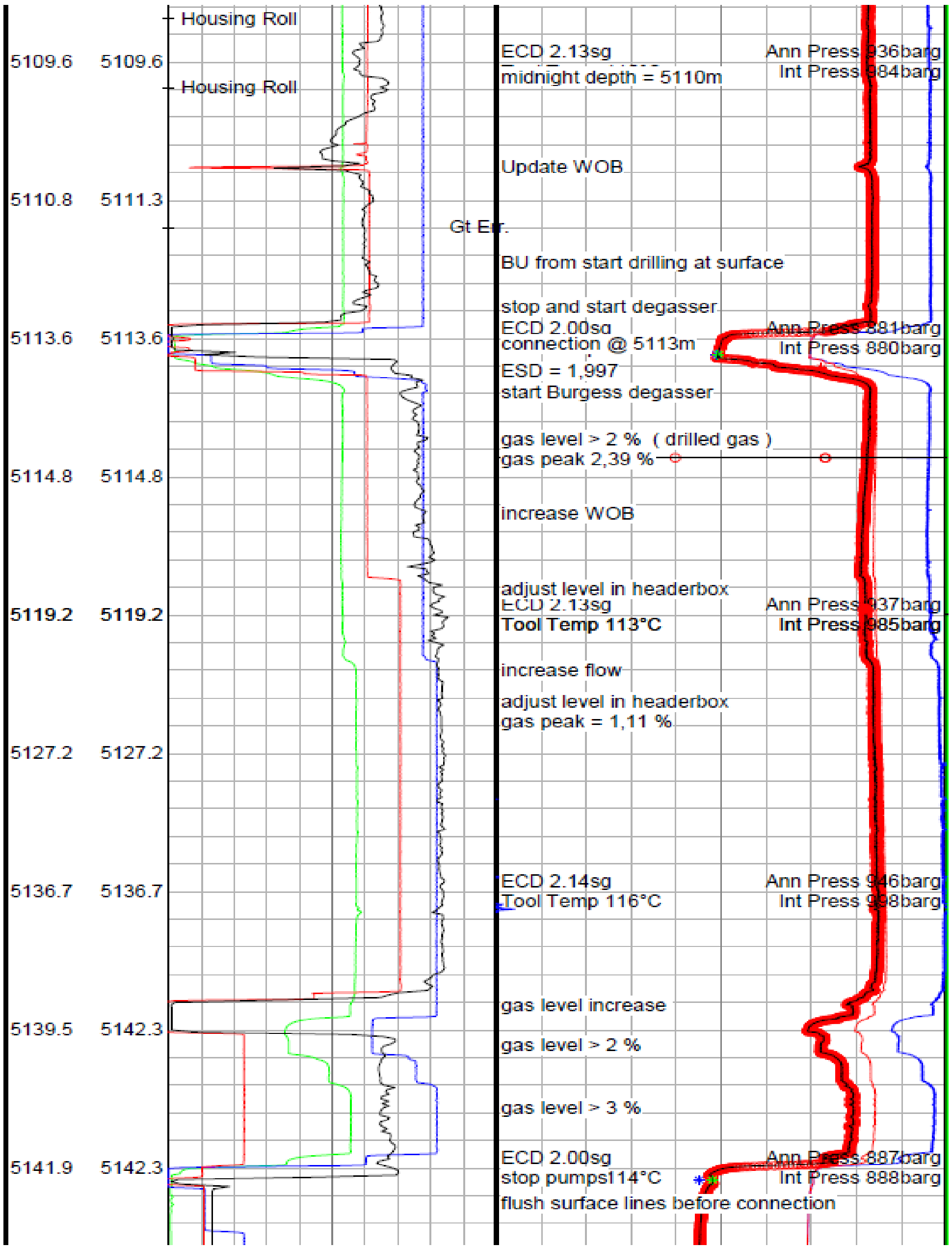


Figure 38: Capture of real-time data from Well A drilling operation from 5109-5142 mMD.

8. Results from evaluation schemes

As a part of the evaluation of the Full Scale Drilling Simulator, evaluation schemes have been handed out to all participants in the period from 08.02.2012 – 10.05.2012. The feedback from participants is an important element for continuously improvement of simulator training and the simulator itself. Unfortunately didn`t all the licenses get the chance to fill out the same evaluation schemes. Hence, Snorre, Tordis and Gudrun have filled out a simplified evaluation form, while Gullfaks, Statfjord and King Lear have filled out a more detailed form. The results are presented for each licensee in Appendix B while section 8.1 presents an overall summary of received feedback with related discussion.

Each licensee has requested training situations that applies to scheduled operations. Accordingly, will each licensee have the opportunity to train on field specific challenges that is relevant for upcoming operations.

8.1 Overall summary of feedback results

The overall summary comprises evaluation of 287 participants divided on 6 different licenses. As each license have been trained on different operational cases and have had different theoretical focus, will this overall summary of feedback results be discussed and summarized with an general focus representative for each licensee.

1. Where the objectives clearly defined at the start?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,4 %	0,4 %	8,1 %	36,1 %	48,1 %	7,0 %

Average score:	4,5

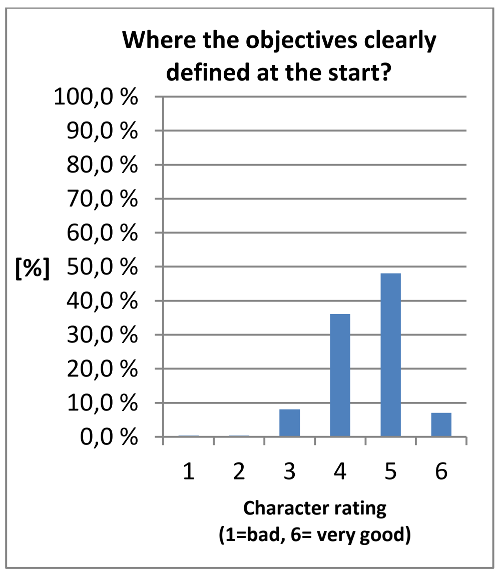


Figure 39: Summarized result of the participant`s comprehension for given task.

Figure 39 illustrates the participants` perception of how well each task was defined. Generally will a good training session require well defined objectives that ensure a common understanding throughout the team. The summarized results shows that an average score of 4,5 out of maximum 6 points are achieved. 7 % of all participants have stated that they have a clear understanding of what the defined objectives were. This result shows that Statoil`s project team needs to look more into how the objectives with each case/task can be communicated with a greater understanding throughout the participants.

In order to ensure that the team works together towards the defined work scope, a proposed improvement is to meet the participants` desire for additional information handed out in advance to training. Since this type of training is new for most participants, will much of the focus be taken towards familiarization with the simulator and the new environment they are trained in. Current practice is that the participants receive descriptions of the simulator and its functions in advance of training. However, the responsibility lies on each participant to spend time going through the description in advance. In order for participants to get the most out of the day, will it be important for the licensee to ensure that participants take the time to prepare and familiarize themselves with applicable information prior to training. Case descriptions with applicable risk register could be presented with simulator description, thus will each participant have the opportunity to familiarize themselves with the cases and equipment that they are to be trained on. A prepared team can contribute to better discussions in the classroom, more involvement during case training and it will ensure a more efficient and engaged team-training due to increased understanding of the tasks to be executed. Instructors' role by introducing the drilling simulator and instruct the personnel through the training can as a consequence be easier since the focus can be related to something the participants have become familiar with in advance.

2. Was the blend of theory and exercises satisfactory?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,4 %	4,6 %	35,6 %	46,6 %	12,8 %

Average score:	4,67

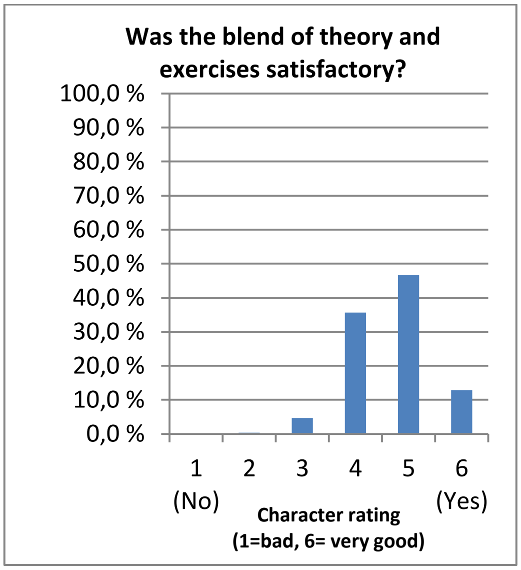


Figure 40: Summarized result for how the blend between theory and exercises have been.

Figure 40 shows the summarized result for how the blend between theory and exercises has been set up. The average score is 4,7 out of maximum 6 points. Each participant desire for more practically/theoretically training turns out to depend on the participants` discipline. Drilling supervisors, drilling engineers and toolpushers` turns out to have a greater interest in theoretical activities compared to driller, assistant driller, cementer and mud engineers which favors practical training. Thus, discussions that arise during classroom activities appear to provide an important learning to everyone.

Hence, as the results illustrate will each participant's preference for theory and practical work varies depending on its position. As both practical and theoretical elements contribute to increased learning and team training is it important to find a good blend for all participants. However, theoretical training in the classroom could have had an even better benefit if each participant could be prepared in advance to the given tasks. Through better understanding and insight into the tasks that is given, would each participant easier follow and contribute to discussions arising during training.

3. Do you feel that your position contributed to the team during simulator training?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	1,5 %	2,5 %	5,9 %	25,2 %	35,1 %	29,7 %

Average score:	4,8

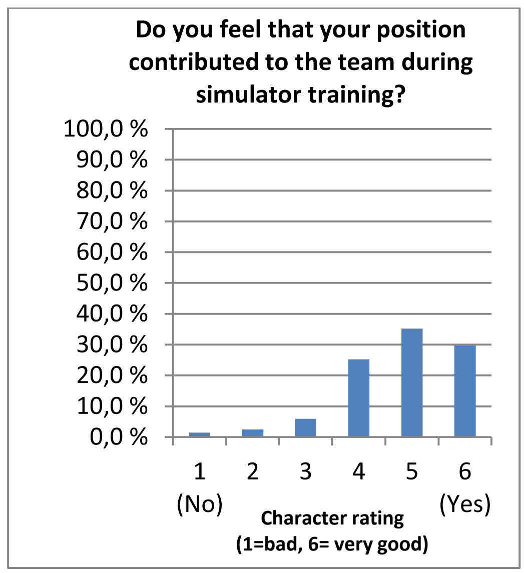


Figure 41: Summarized results illustrating how the participants regarded her/his contribution to the team during training.

Figure 41 illustrates the summarized results for how the participants regarded her/his contribution to the team during training. The average feedback score was 4,8 out of maximum 6 points. As described in section 5.0, is the intended team composition for simulator training the key personnel involved during operational phases. As each participant will have different degree of involvement throughout any operational phase of an operation, is the score reflecting that the most participants contributed during training. With today's setup of training will mud loggers, cementers and drilling engineers not have any pre-defined roles during training. Hence, without defined tasks during operational training can the latter participants easily become passive observers. Even though one can learn something from being an observer, is it important that the participant takes their respective roles and cooperate as a team during training. With defined tasks to every participant will more involvement and engagement be achieved which can enhance the learning curve for everyone.

4. Would you like to be more involved?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	8,5 %	6,5 %	13,1 %	29,6 %	27,6 %	14,6 %

Average score:	4,0

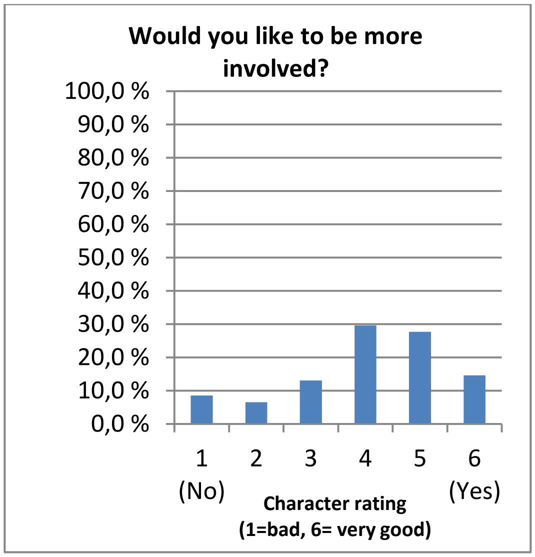


Figure 42: Summarized results illustrating each participant`s desire for more involvement in training.

Figure 42 shows the summarized results for each participant's desire for more involvement in training. The average feedback score was 4,0 out of maximum 6 points. As a score of 3.5 would have indicated an sufficient involvement rating of each participant, can a score of 4,0 be interpreted to be close to an optimal result. However, the feedback shows that the driller, toolpusher and drilling supervisor are the disciplines that don`t want more involvement as they already are involved in every processes during training. On the other side of the score scale, it appears that mud engineers, cementers and drilling engineers often want more involvement. This result can be related to the result seen to question 3 and the comments made to the result.

5. Did the training contribute to increased understanding of well control incidents?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	1,0 %	1,0 %	17,9 %	35,3 %	44,8 %

Average score:	5,2

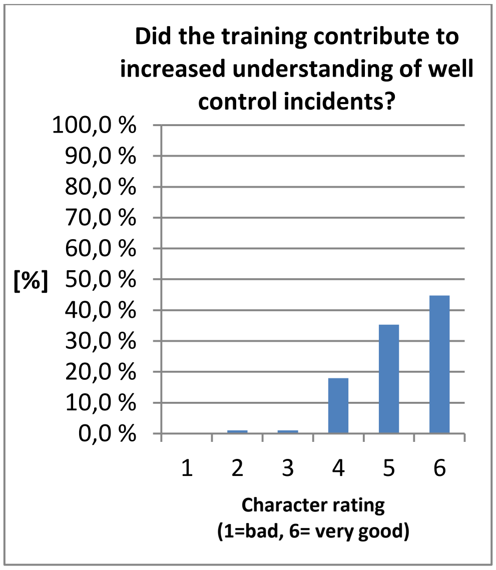


Figure 43: Summarized results illustrating the percentage of participants who experienced an increased understanding through training.

Figure 43 illustrates the summarized results for the percentage of participants who experienced an increased understanding of well control incidents through simulator training. With an average score of 5,2 out of maximum 6 points, shows the result that increased understanding of well control incidents have been achieved. As this is one of the main objectives with simulator training, can it based on the results be concluded that simulator training will increase down hole understanding and thus be an important element to raise company-wide performance. Comments from participants show that through increased down hole understanding have operational elements that previously were not emphasized, now received more attention.

6. How will you evaluate your team`s communication and execution of given task?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	3,5 %	28,1 %	55,3 %	13,1 %

Average score:	4,8

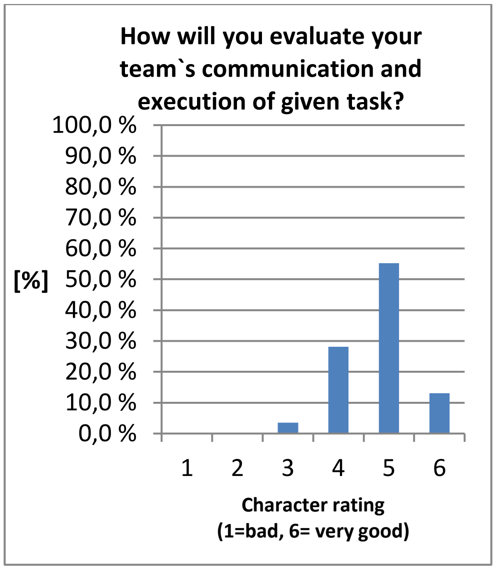


Figure 44: Summarized results illustrating each person's perception of the teams' communication during exercises.

Figure 44 shows the summarized results for how each participant will evaluate the teams' communication through training session. Communication within a team during critical situations can be the determining factor between success or failure. Hence, Statoil has directed an increased focus on communication between key personnel and consequently is this an important focus area during simulator training. Based on the feedback from participant is the average score 4,8 out of maximum 6 points. The score shows that in overall is the communication within a team good, thus having room for improvement. One area that is very important for improvement is to ensure that changes, deviations and operational information is given to all parties involved, so that everyone has the same perception and understanding of the operational situation that is faced.

7. How many days are sufficient for simulator training?

Days	1	2	3
Result	39,8 %	50,3 %	9,9 %

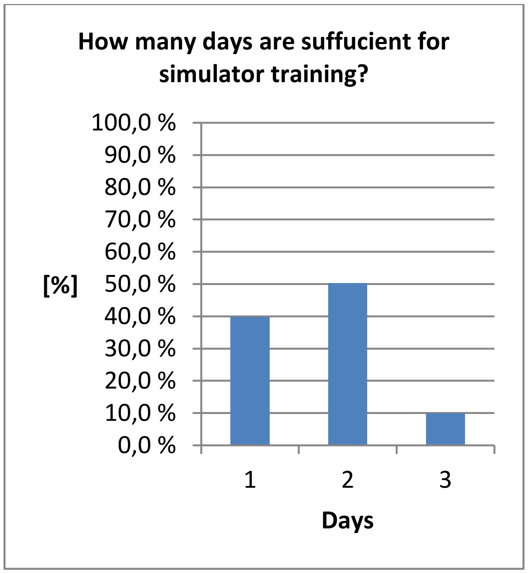


Figure 45: Summarized results illustrating participants preferred length of simulator training.

Figure 45 illustrates the summarized results for preferred length of simulator training. The result shows that 39,8 % think one day is sufficient for simulator training, 50,3 % would preferred two days for training while 9,9 % would prefer 3 days for training. For each drill crew that is to be trained for the first time, will some time be required for familiarization with the new simulator equipment as of today. Based on the feedback from participants can the allocated time be too short, resulting with a focus directed towards the *use* of equipment rather than keeping the focus on the task to be solved. As the purpose of simulator training is *training* on different well situations, will it be important to maintain the focus on training and not fall into a more illustrative focus which easily can be related to traditional courses. Achieving this will require sufficient time for each part of the training that can allow participants to try suggested solutions that can fail, and still get an attempt to solve the task with a correct solution.

More effective training could be achieved through small changes from today's setup. As mentioned earlier have participants requested a description of cases to be trained on in advance to simulator training. This could result in more prepared personnel with a better overview of the tasks to be executed. Thus, each participant needs to take responsible to familiarize themselves in advance, and the licensee needs to follow up that the participants read applicable information in in order to benefit from this action. With a more prepared personnel and shorter duration of transport legs could an increased number of cases be trained on.

Due to limited capacity in the drilling simulator will an expansion from 1 to 2-3 days of training result in fewer licenses having the opportunity to perform training each year. Thus, allocated time for each licensee must be used effectively to achieve the best possible learning outcomes.

8. Would you like to come back for training?			
Character	**Yes**	**Maybe**	**No**
Result	95,2 %	3,7 %	1,1 %

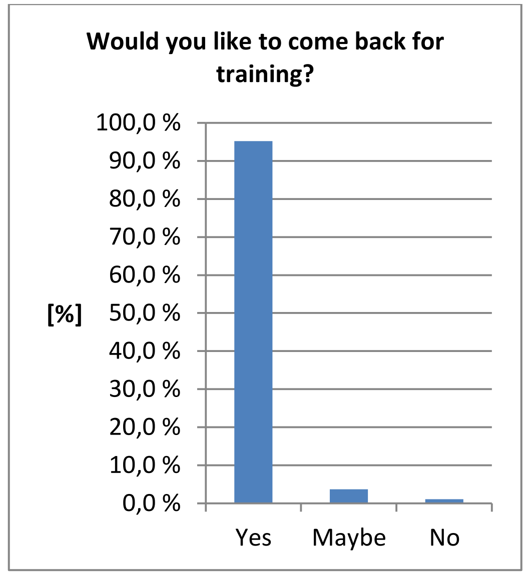


Figure 46: Summarized results illustrating participants' desire of additional simulator training.

Figure 46 illustrates the summarized result for participants` desire to come back for additional simulator training. The overall result shows that 95,2 % of the participants are positive to come back for similar simulator training, 3,7 % answered maybe and 1,1 % answered no. With over 95 % of the participants being positive to more simulator training, have drilling simulator training achieved sufficient interest from drilling- and well crews to further develop this initiative.

9. Have your own expectations been met?						
Character	**1 (No)**	**2**	**3**	**4**	**5**	**6 (Yes)**
Result	0,0 %	0,0 %	4,6 %	35,4 %	48,8 %	11,2 %

Average score:	4,67

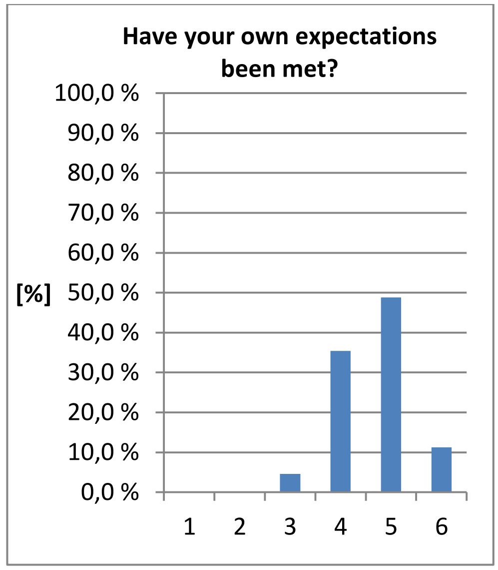


Figure 47: Summarized results illustrating whether participants expectations were met.

Figure 47 summarizes whether participants expectations have been met throughout training in the drilling simulator. The average score is 4,7 out of maximum 6 points. Each participant`s expectation for simulator training will vary in accordance with the references one has from comparable methods of training or other related courses. However, the result shows a small gap between participants` expectations and what one day of training has brought to each participant. Based on the feedback from participants are the following factors highlighted as potential for improvement:

- Technical errors on simulator software
- To long transport legs prior to incidents for some cases
- To short time devoted for each case
- Participants would prefer more cases
- More time for familiarization with simulator equipment
- Visualization of drilling parameters has to low scaling.

10. How would you rate this event overall?						
Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	2,8 %	36,5 %	50,9 %	9,8 %

Average score:	4,68

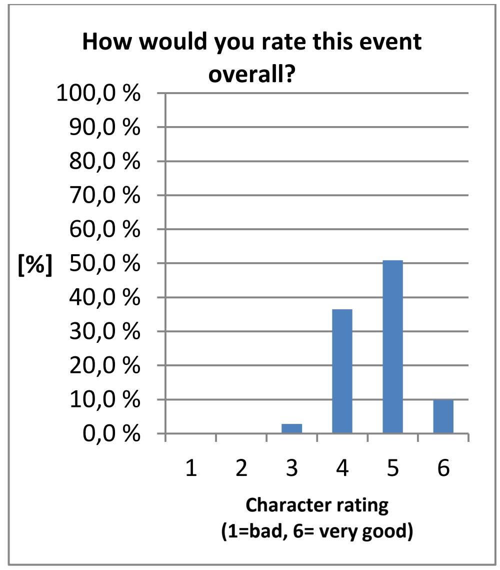


Figure 48: Summarized results illustrating overall rating of simulator training.

Figure 48 summarizes the participants overall rating of simulator training. The average score is 4,7 out of maximum 6 points. The overall evaluation of simulator training reflects a good character rating, with room for some improvements. With the same pinpoints listed above to Figure 93, could these pinpoints explain some arguments for not achieving top score from every participant.

8.8 Comments in the aftermath of simulator training

In the aftermath of completed simulator training, I`ve contacted various drilling supervisors, drilling superintendent, project manager and leading drilling engineers to get their personal feedback on their view of simulator training in a full scale drilling simulator. From this, the following comments emerged:

The average score received from Gullfaks team indicates an overall lower rating compared to the other licensees. This can partly be explained due to an excess number of participants during training. In average was each Gullfaks group nearly twice as large (12-14 participants) compared to other licensees. Sturle Gaassand, Lead Drilling Engineer Gullfaks, comments that the participants who participated indirectly (mud engineer, cementer and drilling engineer) in the cases became too passive in the training and it was difficult with so many crew members to get a good composition/logistics of the groups. Hence, Gaassand points out that this type of training differs from other courses/training programs through training on real events in a near-operational environment.

Bjørn Risvik who is project manager for the drilling simulator from Statoil, states that Statoil and the licensee have a great potential value in the implementation of simulator training to develop operational teams that are better prepared to deal with common and critical operations. He points out that this will contribute to the right focus during operation, which will result in fewer errors and thus ensure more effective operations. Risvik also highlights that this type of training differs from other types of courses/training through training the team as one unit and that the training is tailored to each license specific challenges.

Drilling supervisor at Gullfaks A, Clas-Erik Stomberg, have also completed simulator training with his own crew. Stomberg points out the importance and potential of being able to train in such a realistic environment, where each individual makes knowledge sharing of their personal skills with the goal of preventing both small and large accidents. He states that this will contribute to better economy and reputation for Statoil, and not least is this an important risk reducing action. The statement is supported by drilling superintendent at Snorre B, Inger Kjellevoll. Kjellevoll also points out the importance of the discussions that occur both during and after training which helps to increase the overall downhole understanding for everyone.

9. Summary and conclusion

Statoil have in cooperation with SINTEF Petroleum Research, eDrilling and Oiltec Solutions developed a Full Scale Drilling Simulator for operational training of drilling and well personnel. Throughout the period from January - June there have been 40 classes of training which have formed the basis of my evaluation of simulator training and its potential for training in Managed Pressure Drilling (MPD) mode.

This thesis has given a general introduction to conventional drilling and a more detailed literature study of MPD system. The MPD module is about to be implemented in the drilling simulator and will form the basis for all simulator training together with the conventional drilling module. For both modules have related drilling problems been addressed, and the handling of them have been highly relevant for all the licenses that have performed training in the simulator. This thesis has also given a detailed description of the full scale drilling simulator setup and how the simulator is build up. Thus, this type of training is proving to be a service that the drilling and well personnel have longed-for. Based on feedback from the personnel that have completed simulator training, shows the results that 95,2 % of the personnel wants to come back for relevant training again.

Hence, simulator training can help to identify problems and its consequence. When problems are identified will simulator training enable testing of possible solutions with illustration of applicable response. For both experienced and inexperienced personnel will this be an useful learning. Driller and assistant driller are the operators of rig equipment during simulator training, and based on their feedback are they very positive and impressed on how realistic the equipment react and responds. However, the feedback shows that the given time to familiarize themselves with simulator setup can be too small causing the focus to be moved towards operation of the simulator rather than focusing on case handling.

Operational parameters (pit volumes, ECD, SPP, etc.) downhole are visualized through eDrilling`s own visualization software. The scaling of displayed parameters turns out to be too small according to received feedback from participants. This makes interpretation of trends and readings of parameters more complicated than necessary.

The organization of simulator training has also been evaluated by the participants. It turns out that the length of training compared to its content has a wide spread in opinions. This can be explained by the variation in type of cases that are given to each license and the engagement of each team during training. The feedback results regarding optimal length of simulator training shows that 39,8 % think one day is sufficient, 50,3 % preferred two days of training and 9,9 % would preferred 3 days of training. The arguments for extending the training for more than one day are to use day one to familiarize with simulator equipment’s and case preparation, while day number two is used to case training in the drilling simulator. The most important argument for extending the training is to bear in mind that this is a training simulator, not a course that is to be passed. For participants to be trained, will it be important that the participants get the opportunity to try and fail on operational cases. Elsewhere will the training be characterized as more illustrative and a way of introducing the personnel to upcoming tasks that is to come. It should be noted that each team spends much time to familiarize themselves with the equipment, and the focus is easily directed towards the equipment rather than operation.

Based on the participants' feedback is operational training providing the most learning for the teams. The performed training in a quiet environment where KPI are absent, makes the participants reflecting over the situation they stand in and through this can discussions and illustrations give a better downhole understanding. On a general basis are discussions providing knowledge sharing for the whole team, which in turn brings value to all participants. Hence, it is important that discussions that arise during training gets caught up in a way that makes it possible to take experiences and improvements further into the organization. Otherwise it's hard for the management group to take further actions and ensure knowledge sharing / improvements within the team. A suggestion will be to announce the drilling engineer as responsible to make a summary of the simulator training with special emphasize on discussions and other operational comments that can be valuable for the team.

One of Statoil's` objective by implementing simulator training is to improve the drill crews' ability to identify serious hazards early and learn to correct the operation accordingly. Whether this objective is achieved is difficult to conclude. Hence, it turns out that 80,1 % have scored 5 or 6 for improved downhole understanding after training. It also turns out that participants are more aware and reflected around elements that have had little focus earlier.

The numbers of participants during simulator training have varied from 4-14 attendees. The team composition has varied throughout training, but with some exemptions have the key personnel always been present. How much benefit each participant receives from simulator training will vary depending on the discipline each individual possesses. It turns out that for the driller, assistant driller, drilling supervisor and toolpusher is the highest benefit achieved around specific case training in the simulator. For drilling engineers, mud loggers and cementers it seems as their participation often ends up as passive observers with no defined tasks. Hence, the feedback shows that the latter participants achieve increased downhole understanding and increased understanding of operational procedures from training in the simulator. The recommendation will be to look into the possibility of defining specific tasks to all participants which will ensure more involvement and engagement from everyone.

The overall score of simulator training in the Full Scale Drilling Simulator is an average of 4,7 out of a maximum of 6 points. With respect to that this highly advanced full scale drilling simulator is newly developed, it must be expected that the simulator can run into smaller technical problems during training. However, technical problems that arise during training must be resolved immediately since the focus on training is taken away when technical issues arise.

Another objective with simulator training is to perform training on relevant drilling and well operations. Since the capacity of simulator training is already overbooked, will most of licenses only have one training period each year. To enhance the training objective, I would propose to focus more attention to training objectives and more efficient case training. This implies that more information about the cases should be released in advance of the training, which will enhance discussions in "the office" section before the practical operations are carried out in the drilling simulator. Thus, it is recommended that transport legs are cut down and replaced with more "straight-to-the-point" case training with increased number of cases.

Managed Pressure Drilling (MPD) operations are more complex and different compared to conventional drilling. Hence, Statoil requires that all personnel that are to take part of MPD operations fulfill the requirements for interactive training. According to ARIS, the governing system to Statoil, is the requirement that the personnel have completed training in three different steps as a minimum requirement. Thus, simulator training will be an important element in qualifying competent personnel prior to operations. Since MPD equipment's can be unknown for drilling personnel, will training in a safe environment ensure effective training on the right objectives. In addition will simulator training reduce the need for offshore training out on the rig, and the drill crew gets a chance to train as a team with focus on communication and field related challenges. The simulator has a unique flexibility that ensures that MPD components can be modeled into the topside simulator, which enables any 3. party MPD control system to be integrated.

Evaluation of ECD calculations performed with Drillbench and SINTEF`s downhole simulator, Intellectus, shows that both simulator tool are aligned and simulates consistent and coincide results. The simulated values showed an deviation of 0,005 – 0,007 sg. This is an important result for Statoil as their operational plans are conducted and based on simulations performed with Drillbench/Wellplan. The simulated results seen during simulator training were not applicable for direct comparison due to operational changes of drilling parameters that made comparison unreasonable. Hence, a simulation batch was set up based on parameters seen during real-time operation as a test of Drillbench`s reliability. The simulated results were aligned and thus strengthening the view of being a realistic simulation tool and a credible tool for planning operations. Thus, this result illustrates as a consequence that performed training in the drilling simulator will hold the same strength and weaknesses as the planning tools operated on the daily basis for the engineers.

Abbreviations

BHA	Bottom Hole Assembly
BHP	Bottomhole Pressure
BOP	Blowout Preventer
BP	Back Pressure
BPP	Back Pressure Pump
CBHP	Constant Bottom-hole Pressure
CCS	Continuous Circulation System
DAS	Data Acquisition System
DG	Dual Gradient
ECD	Equivalent Circulation Density
ERD	Extended Reach Drilling
ESD	Equivalent Static Density
HPHT	High Pressure High Temperature
IADC	International Association of Drilling Contractors
ID	Inner diameter
MPD	Managed Pressure Drilling
MPO	Managed Pressure Operations
MW	Mud Weight
MWD	Measurement While Drilling
NPT	Non-Productive Time
NRV	Non-return Valve
OD	Outer Diameter
PCWD	Pressure-Control-While-Drilling
PMCD	Pressurized Mud-Cap Drilling
POD	Plan of Development
PSV	Pressure Safety Valve
PVT	Pressure, Volume and Temperature
RCD	Rotating Control Device
ROP	Rate of Penetration
RPM	Revolutions Per Minute
sg.	Specific Gravity
SPT	Scanpower Petroleum Technology
TD	Target Depth
TTRD	Through Tubing Rotary Drilling
TVD	True Vertical Depth
UBD	Underbalanced Drilling
UIS	University of Stavanger
WHP	Wellhead Pressure
WOB	Weight on Bit

References

[1] Statoil ASA, «Advanced drilling simulator - Youtube,» Statoil ASA, [Internett]. Available: http://www.youtube.com/watch?v=k5PUOgLSj8U.

[2] Standard.no, «Norsok D-010».

[3] DrillingForumals.com, «Introduction to drilling hydraulics,» [Internett]. Available: http://www.drillingformulas.com/introduction-to-drilling-hydraulics/.

[4] B. Rehm, J. Schubert, A. Haghshenas, A. S. Paknejad og J. Hughes, «Managed Pressure Drilling,» *Gulf Drilling Series.*

[5] Statoil ASA, «ARIS/APOS - Well Barrier Schematic».

[6] S. Charles R. "Rick" Stone og S. S. E. C. Shifeng Tian, «Sometimes Neglected Hydraulic Parameters of Underbalanced and Managed Pressure Drilling,» *SPE/IADC 114667,* 2008.

[7] Halliburton, «Norway Autochoke Equipment Sales Brochure rev3,» *Internal documents.*

[8] J. Haugstad og D. O. Molde, «MPD General_OTC_2010 (Internal document)».

[9] J. Jenner, H. Elkins, F. Springett, L. P.G. og J. and Wellings, «The continuous circulation system: An advance in constant-pressure drilling,» *SPE 90702,* 2004.

[10] «Subsea and Offshore Engineering - Continous Circulation Drilling System,» Maris, [Internett]. Available: http://www.maris-eu.com/ccd.html.

[11] F. Varpe, B. Risvik, D. O. Molde, S. Hovland, ASA og S. Bjørn Risvik, «Realistic MPD Training in Advanced Drilling Simulator,» SPE/IADC Managed Pressure Drilling & Underbalanced Operations Conference & Exhibition - March 2012.

[12] Statoil ASA, «Competence management drilling and well (Internal document)».

[13] D. O. Molde, "Drilling Simulator Course Introduction (Statoil internal document)".

[14] E. Gao, M. Booth og N. MacBeath, «Continued Improvements on High Pressure/High Temperature Drilling Performance on Wells With Extremely Narrow Drilling Windows – Experiences From Mud Formulation to Operational Practices, Shearwater Project,» *IADC/SPE 59175.*

[15] T. N.Karlsen og H. C. Karlsen, «Risk Based Decision Support for the Planning of a Challenging HPHT Drilling Operation,» *IPTC 12526.*

[16] B. Risvik, «Drilling Simulator Presentation,» *Internal Statoil Document,* 2011.

[17] R. Rommetveit, K. S. Bjørkevoll og et.al., «A System for Real-Time Drilling Simulation, 3D Visualization and Control,» *SPE 106903,* 2007.

[18] SINTEF, eDrilling and OILTEC Solutions, «Intellectus hiDRILL - Integrated Well Training Simulator».

[19] J. Petersen, S. Rolv Rommetveit, S. Knut S. Bjørkevoll, J. Frøyen og S. P. Research, «A General Dynamic Model for Single and Multi-phase Flow Operations during Drilling, Completion, Well Control and Intervention,» 2008.

[20] S. Z. Kassab, A. S. Ismail og M. M. Elessawi, «Drilling Fluid Rheology and Hydraulics for Oil Fields,» *European Journal of Scientific Research,* nr. ISSN 1450-216X Vol.57 No.1 (2011).

[21] Schlumberger, «Oilfield Glossary,» [Internett]. Available: http://www.glossary.oilfield.slb.com/Display.cfm?Term=Herschel-Bulkley%20fluid.

[22] B. S. Aadnøy, Modern Well Design, Second edition, 2010.

[23] Wikipedia, «Torque,» [Internett]. Available: http://en.wikipedia.org/wiki/Torque.

[24] K. Bjørkevoll, R. Rommetveit, A. Rønneberg og B. Larsen, «Successful Field Use of Advanced Dynamic Models,» *IADC/SPE 99075.*

[25] K. S. Bjørkevoll, D. O. Molde, R. Rommetveit og S. Syltøy, «MPD Operation Solved Drilling Challenges in a Severely Depleted HP/HT Reservoir,» *SPE/IADC 112739,* nr. IADC/SPE Drilling Conference, Orlando, Florida, 2008.

[26] SPT Group, «Drillbench,» [Internett]. Available: http://www.sptgroup.com/en/Products/Drillbench/.

[27] S. Syltøy, S. Eide, S. Torvund, P. Berg, T. Larsen, H. Fjeldberg, K. Bjørkevoll, J. McCaskill, O. Prebensen og E. and Low, «Highly advanced multitechnical MPD concept extends achievable HPHT targets in the North Sea,» *Paper SPE/IADC 114484.*

[28] D. Chowdhury, P. Skalle og M. M. Rahman, «Prediction of Stand Pipe Pressure using conventional approach,» *Chemical Engineering Research,* 2009.

[29] B. Rehm, J. Schubert, A. Hagshenas, A. Paknejad og J. and Hughes, «Gulf Drilling Series - Managed Pressure Drilling,» *Gulf Publishing Company,* 2008.

[30] Statoil ASA, «ARIS/APOS - Well Barrier Schematic (Internal documents)».

[31] K. P. Malloy, C. R. Stone, G. H. Medley, D. Hannegan, O. Coker, D. Reitsma og H. Santos, «Managed-Pressure Drilling: What It Is and What It Is Not,» *IADC/SPE 122281*, 2009.

Appendix A – Evaluation scheme I

Statoil

EVALUATION OF DRILLING SIMULATOR TRAINING

This evaluation scheme is made as part of a master thesis at the University of Stavanger. The topic of the thesis is "Evaluation of a full scale drilling simulator". Please fill out this scheme as accurate as possible and help us to develop further this simulator. This will give you a better experience next time you are to be trained.

Your position (Drilling supervisor, Toolpusher, Driller, Ass. Driller, Mud logger, drilling engineer, etc.):						
You can choose to answer in both Norwegian and English.						
Evaluation	**1 (No)**	**2**	**3**	**4 (Partially)**	**5**	**6 (Yes)**
Do you feel that your position contributed to the team during simulator training?						
Would *you* like to be more involved?						
Did the training contribute to increased understanding of well control incidents?						
How will you evaluate your team`s communication and execution of given tasks?						
What part of the training provided the most value to you? Why?						
How do you consider the size of the team? If you consider the team size to large/few, who was redundant/missing?						
If you could choose on a general basis, list two scenarios that you would prefer to be trained on in order to improve your skills:						
How was the length of the training compared to its content?						
Was one day sufficient for training, or would you prefer 2 or 3 days of continuous training?						
Would you like to come back for training?						
Give one suggestion for improvement of training:						

Figure 49: Evaluation scheme I.

Appendix B – Evaluation scheme II

Statoil

Feedback on seminars, courses and conferences

Title of seminar/course/conference	Start		Close	
	Day	Month	Day	Month
Participant				
Your feedback will be of great value to us in improving this particular event. Please complete the form as accurately as possible and return to the person in charge.				

General	Poor			Excellent		
How would you rate this event overall?						
Have your own expectations been met?						

Objectives	Poor			Excellent		
Were the objectives clearly defined at the start?						
Have your own expectations been met?						

Implementation	Poor			Excellent		
How would you rate the documentation?						
Was the blend of theory and exercises satisfactory?						
How were the premises?						
Practical matters (accommodation, transport etc.)						

Lecturer's performance		Poor			Excellent		
Are you satisfied with the professional content and pedagogic performance?							
Instructor 1:	Content						
	Performance						
Instructor 2:	Content						
	Performance						
Instructor 3:	Content						
	Performance						
Instructor 4:	Content						
	Performance						
Instructor 5:	Content						
	Performance						
Instructor 6:	Content						
	Performance						

Figure 50: Evaluation scheme II.

Appendix C – Results from evaluation schemes

Gullfaks training

The results from Gullfaks simulator training is based on 116 participants.

Simulator training was performed on the following situations:

1. Mechanical stuck
2. Loss
3. Kick
4. Swabbing in gas during trip out

Each participant had the opportunity to respond/evaluate 10 different questions related to performed simulator training. Each question could be graded from 1-6, where 1 is the lowest score (bad) and 6 is the highest (very good). The overall results from Gullfaks are as follows:

1. Where the objectives clearly defined at the start?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,9 %	10,5 %	42,1 %	43,9 %	2,6 %

Average score:	4,4

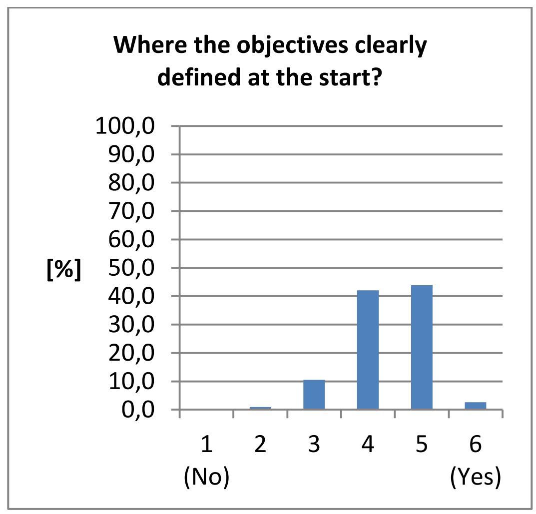


Figure 51: Results illustrating the participants' comprehension for given tasks.

2. Was the blend of theory and exercises satisfactory?						
Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	8,9 %	46,4 %	39,3 %	5,4 %

Average score:	4,4

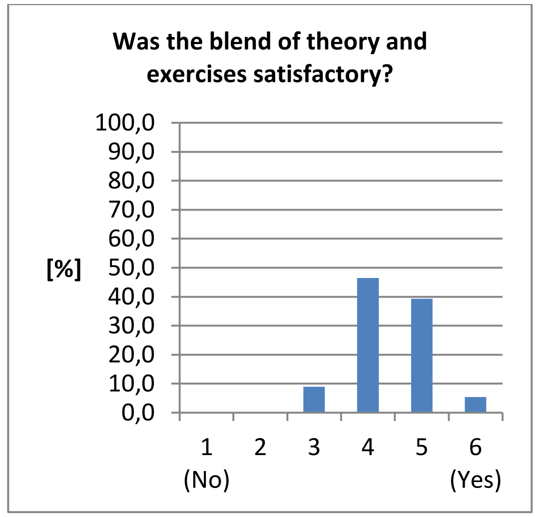


Figure 52: Results illustrating how good the blend between theory and exercises were.

3. Do you feel that your position contributed to the team during simulator training?						
Character	1 (No)	2	3	4	5	6 (Yes)
Result	1,7 %	1,7 %	7,8 %	31,9 %	34,5 %	22,4 %

Average score:	4,6

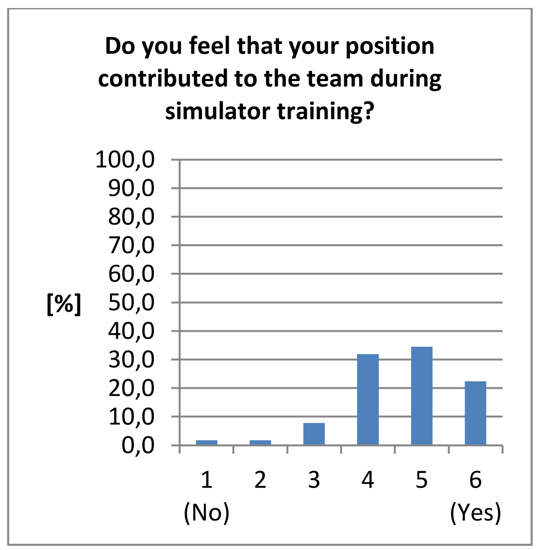


Figure 53: Results illustrating how the participants regarded her/his contribution to the team during training.

4. Would you like to be more involved?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	6,1 %	5,2 %	13,0 %	34,8 %	27,8 %	13,0 %

Average score:	4,1

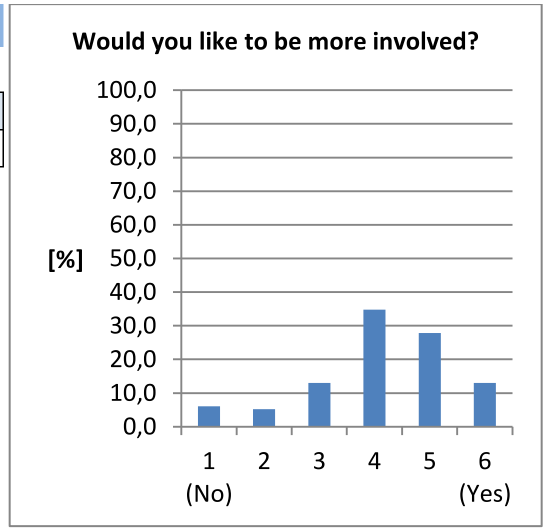


Figure 54: Results illustrates the participants` desire for more involvement in training.

5. Did the training contribute to increased understanding of well control incidents?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	1,7 %	0,9 %	20,9 %	37,4 %	39,1 %

Average score:	5,1

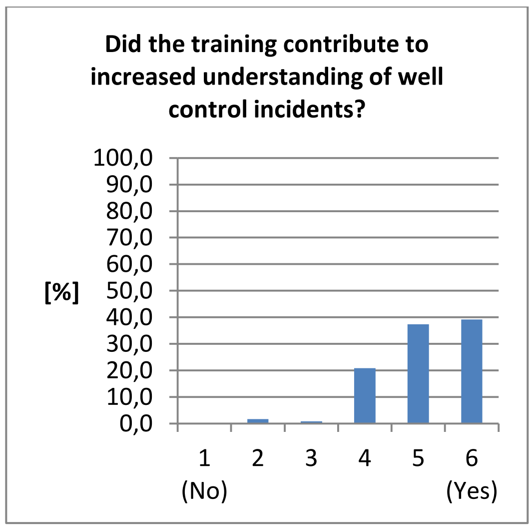


Figure 55: Results illustrating percentage of participants who experienced an increased understanding through training.

6. How will you evaluate your team`s communication and execution of given task?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	3,5 %	30,4 %	55,7 %	10,4 %

Average score:	4,7

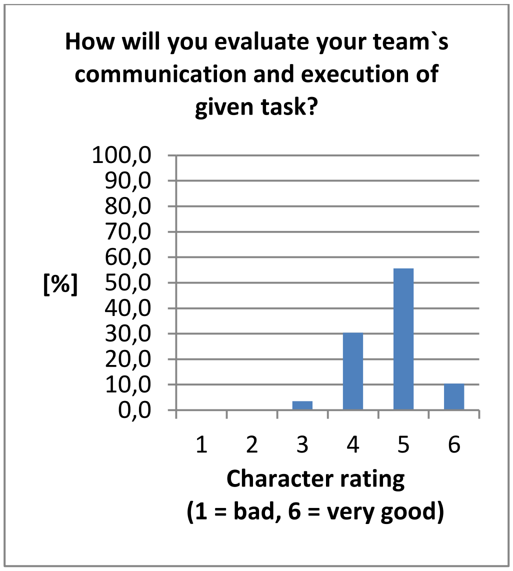


Figure 56: Results illustrating each person`s perception of the team`s communication during the exercises.

7. How many days are sufficient for simulator training?

Character	1 day	2 days	3 days
Result	38,7 %	46,2 %	15,1 %

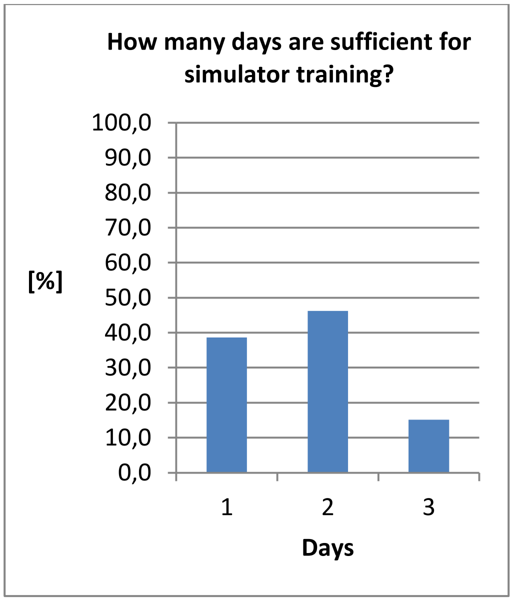


Figure 57: Results illustrating participants preferred length of simulator training.

8. Would you like to come back for training?			
Character	**Yes**	**Maybe**	**No**
Result	92,5 %	5,6 %	1,9 %

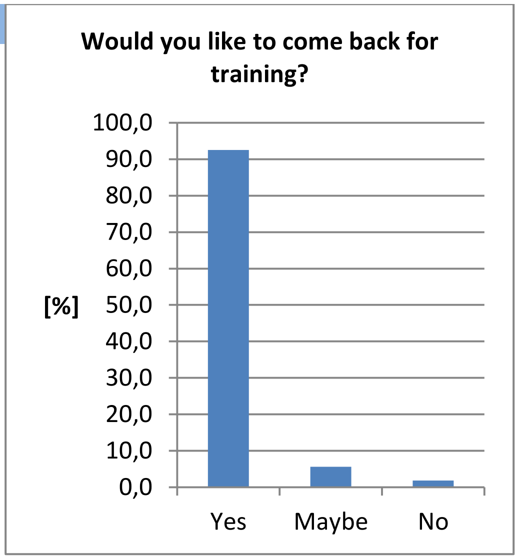


Figure 58: Results illustrating participants' desire of additional simulator training.

9. Have your own expectations been met?						
Character	**1 (No)**	**2**	**3**	**4**	**5**	**6 (Yes)**
Result	0,0 %	0,0 %	6,1 %	51,8 %	36,8 %	5,3 %

Average score:	4,4

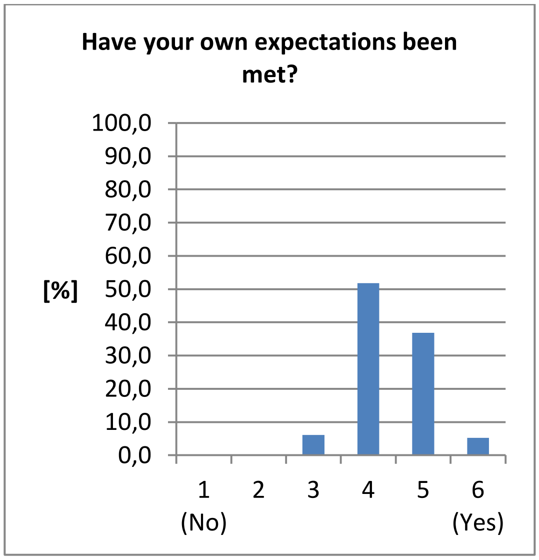


Figure 59: Results illustrating if participants expectations were met.

10. How would you rate this event overall?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	5,3 %	51,8 %	42,1 %	0,9 %

Average score:	4,5

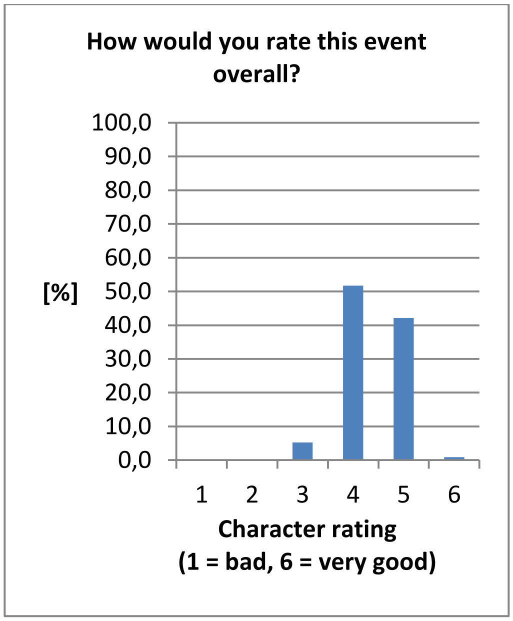


Figure 60: Results illustrating overall rating of simulator training.

Gudrun training

The results from evaluation schemes from Gudrun training is based on 8 participants.

Gudrun drilling & well team performed training on handling of the following situations in the simulator:

1. Gas kick
2. Loss resulting in kick (underground blow-out)

Each participant had the opportunity to respond/evaluate 10 different questions related to performed simulator training. Each question could be graded from 1-6, where 1 is the lowest score (bad) and 6 is the highest (very good). The overall results from Gudrun are as follows:

1. Where the objectives clearly defined at the start?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	0,0 %	25,0 %	75,0 %	0,0 %

Average score:	4,75

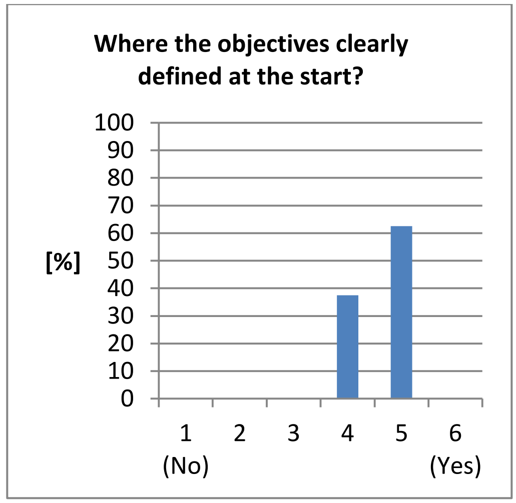


Figure 61: Results illustrating participants' comprehension for given tasks.

---

2. Was the blend of theory and exercises satisfactory?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	0,0 %	37,5 %	62,5 %	0,0 %

Average score:	4,625

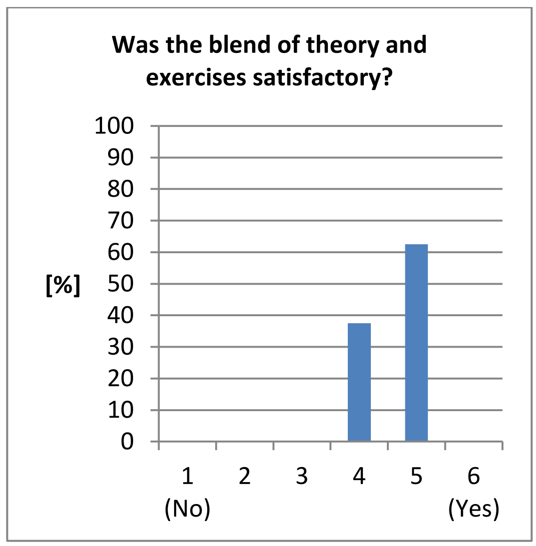


Figure 62: Results illustrating how good the blend between theory and exercises were.

3. Have your own expectations been met?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	0,0 %	25,0 %	75,0 %	0,0 %

Average score:	4,75

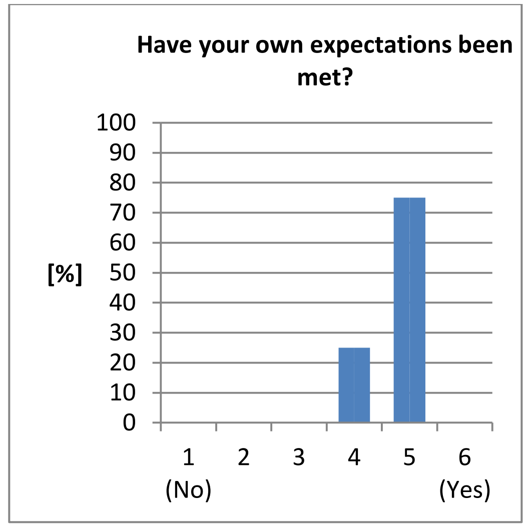


Figure 63: Results illustrating if participants expectations were met.

---

1. How would you rate this event overall?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	0,0 %	25,0 %	75,0 %	0,0 %

Average score:	4,75

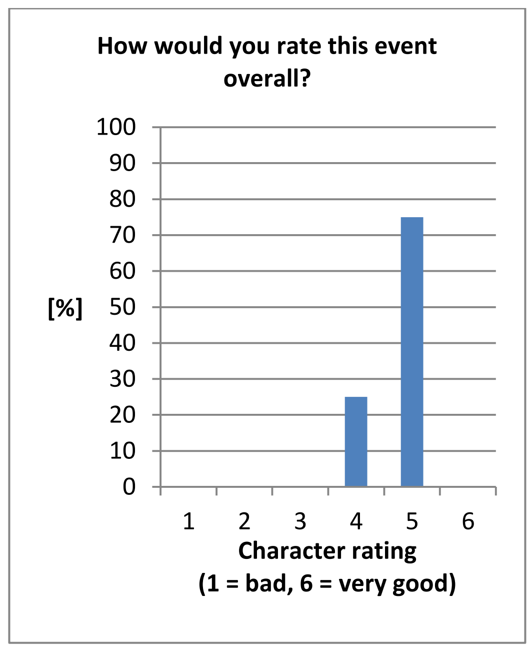


Figure 64: Results illustrating overall rating of simulator training.

Snorre training

The results from evaluation schemes from Snorre training is based on 33 participants.

Snorre drilling & well team performed training on handling of the following situations in the simulator:

1. Loss situation (Stuck pipe if not moving pipe during curing loss)
2. Influx during connection

Each participant had the opportunity to respond/evaluate 10 different questions related to performed simulator training. Each question could be graded from 1-6, where 1 is the lowest score (bad) and 6 is the highest (very good). The overall results from Snorre are as follows:

1. Where the objectives clearly defined at the start?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	0,0 %	27,3 %	63,6 %	9,1 %

Average score:	4,8

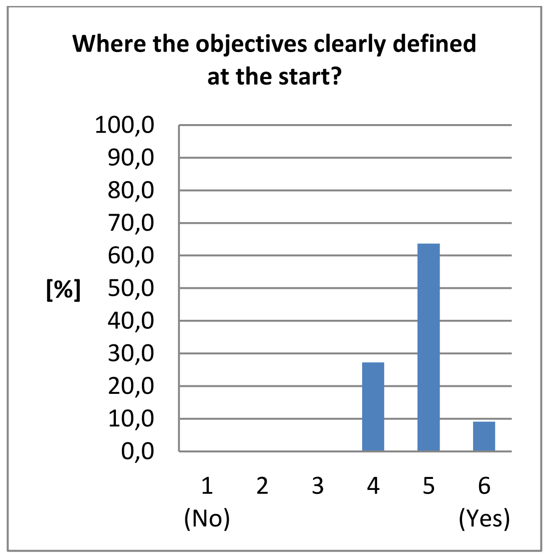


Figure 65: Results illustrating participants' comprehension for given tasks.

2. Was the blend of theory and exercises satisfactory?						
Character	**1 (No)**	**2**	**3**	**4**	**5**	**6 (Yes)**
Result	0,0 %	0,0 %	0,0 %	21,2 %	69,7 %	9,1 %

Average score:	4,9

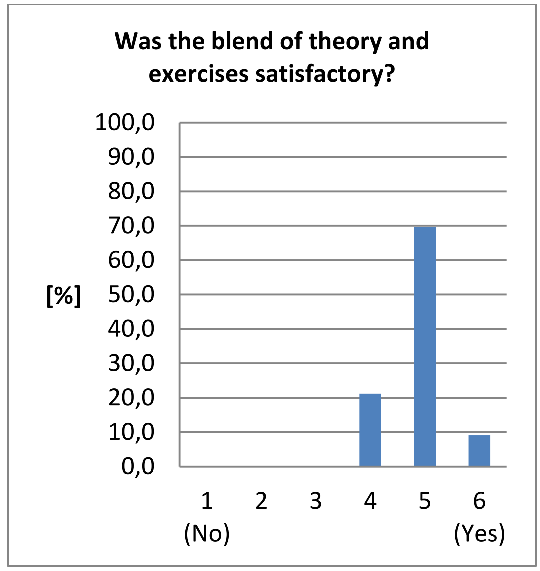


Figure 66: Results illustrating how good the blend between theory and exercises were.

3. Have your own expectations been met?						
Character	**1 (No)**	**2**	**3**	**4**	**5**	**6 (Yes)**
Result	0,0 %	0,0 %	3,0 %	27,3 %	60,6 %	9,1 %

Average score:	4,8

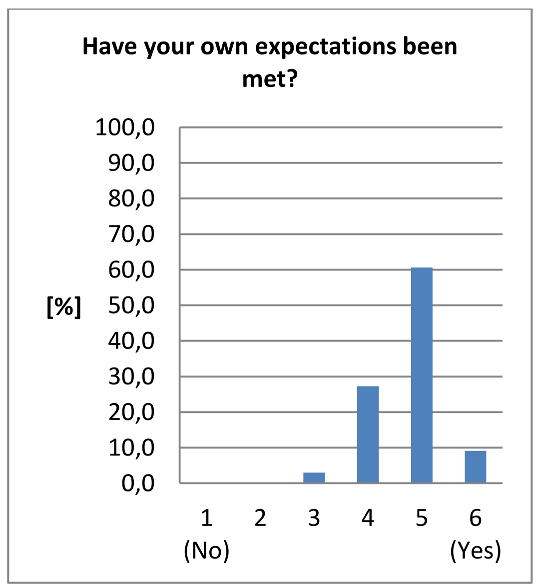


Figure 67: Results illustrating if participants expectations were met.

4. How would you rate this event overall?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	0,0 %	15,2 %	72,7 %	12,1 %

Average score:	5,0

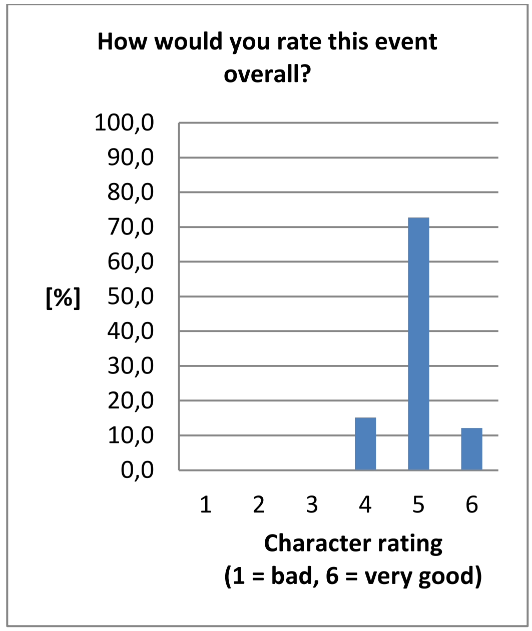


Figure 68: Results illustrating overall rating of simulator training.

Tordis training

The results from evaluation schemes from Tordis simulator training is based on 36 participants.

Gullfaks drilling & well team performed training on handling of the following situations in the simulator:

1. Loss situation (Stuck pipe if not moving pipe during curing of loss)
2. Influx during connection

Each participant had the opportunity to respond/evaluate 10 different questions related to performed simulator training. Each question could be graded from 1-6, where 1 is the lowest score (bad) and 6 is the highest (very good). The overall results from Tordis are as follows:

1. Where the objectives clearly defined at the start?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	2,8 %	0,9 %	8,3 %	22,2 %	52,8 %	13,9 %

Average score:	4,6

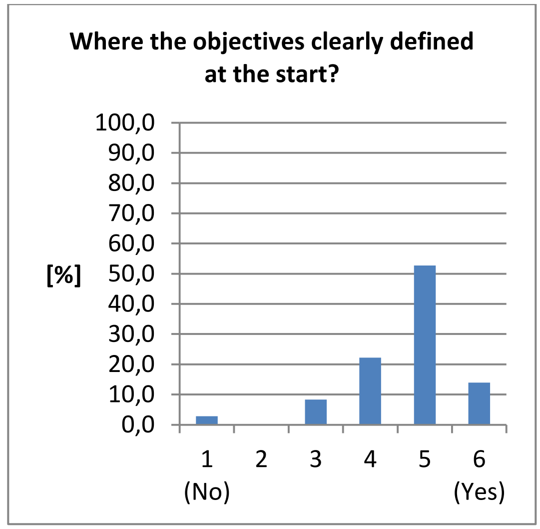


Figure 69: Results illustrating the participants' comprehension for given tasks.

---

2. Was the blend of theory and exercises satisfactory?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	0,0 %	28,6 %	37,1 %	34,3 %

Average score:	5,1

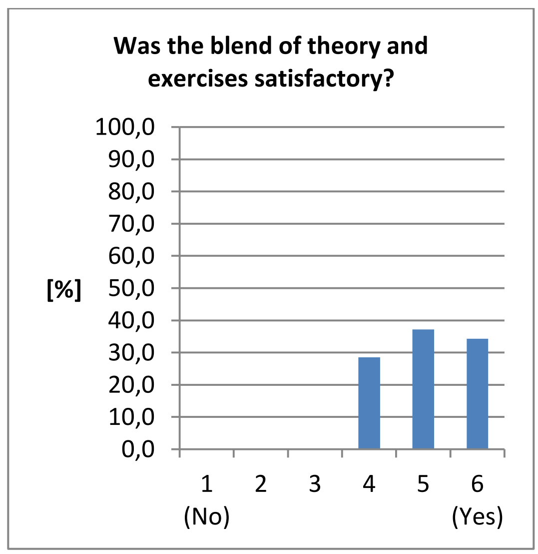


Figure 70: Results illustrating how good the blend between theory and exercises were.

---

3. Do you feel that your position contributed to the team during simulator training?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	7,1 %	0,0 %	0,0 %	21,4 %	35,7 %	35,7 %

Average score:	4,9

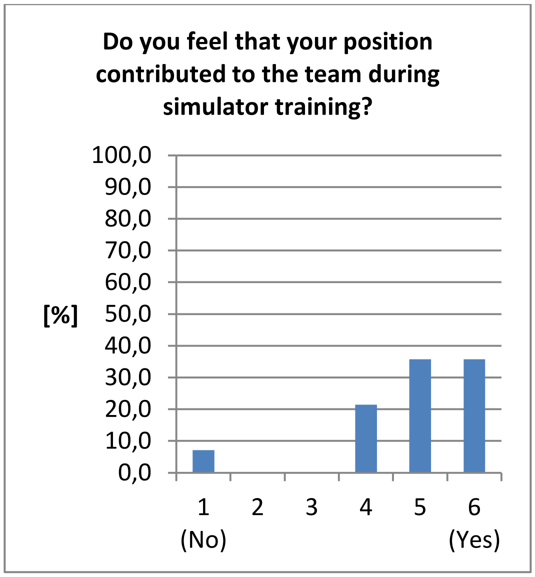


Figure 71: Results illustrating how the participants regarded her/his contribution to the team during training.

---

4. Would you like to be more involved?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	7,7 %	15,4 %	7,7 %	7,7 %	46,2 %	15,4 %

Average score:	4,2

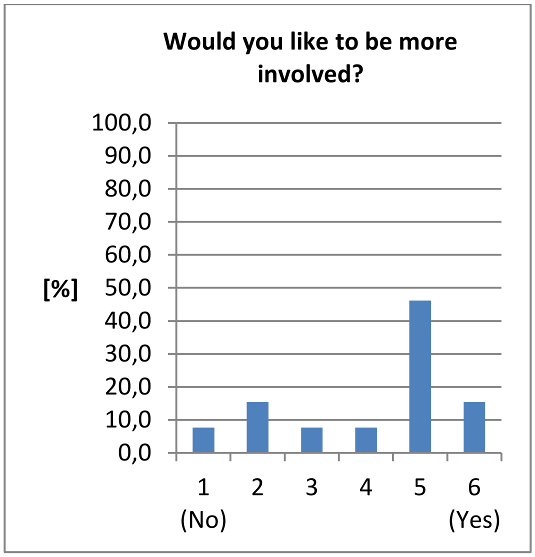


Figure 72: Results illustrates the participants` desire for more involvement in training.

5.	Did the training contribute to increased understanding of well control incidents?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	0,0 %	35,7 %	35,7 %	28,6 %

Average score:	4,9

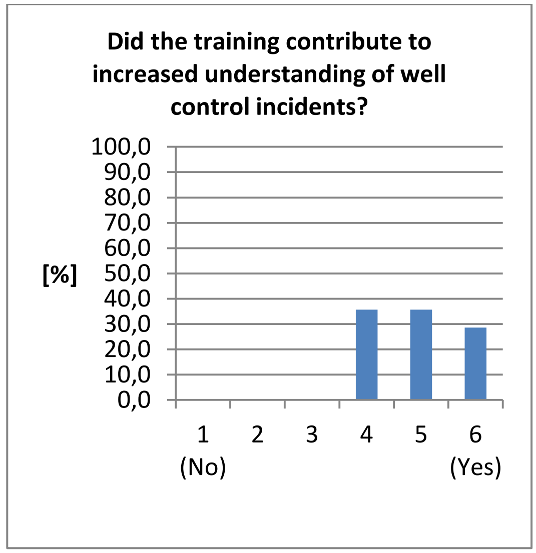


Figure 73: Results illustrating percentage of participants who experienced an increased understanding through training.

6.	How will you evaluate your team`s communication and execution of given task?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	0,0 %	14,3 %	71,4 %	14,3 %

Average score:	5,0

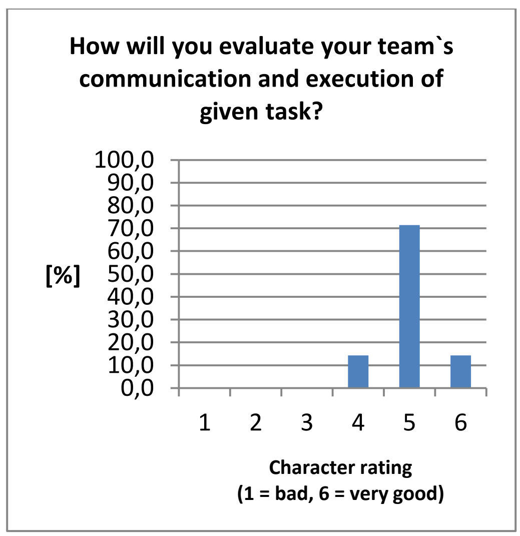


Figure 74: Results illustrating each person`s perception of the team`s communication during the exercises.

7. How many days are sufficient for simulator training?

Character	1 day	2 days	3 days
Result	12,5 %	87,5 %	0,0 %

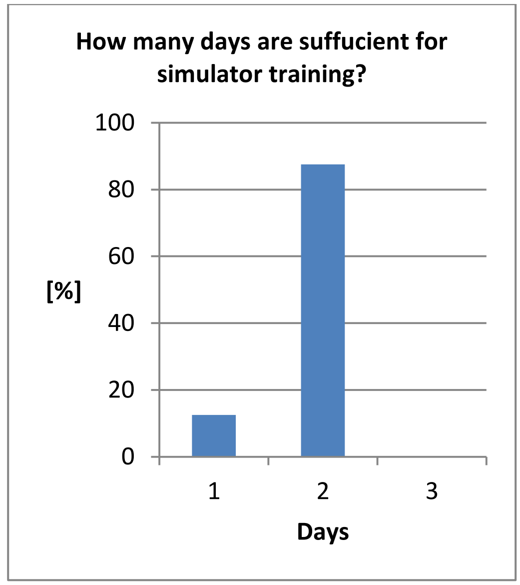


Figure 75: Results illustrating participants preferred length of simulator training.

8. Would you like to come back for training?

Character	Yes	Maybe	No
Result	92,3 %	7,7 %	0,0 %

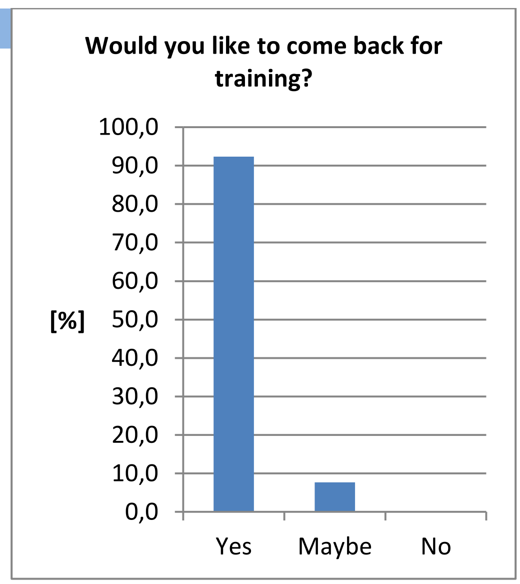


Figure 76: Results illustrating participants' desire of additional simulator training.

9. Have your own expectations been met?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	11,1 %	13,9 %	55,6 %	19,4 %

Average score:	4,8

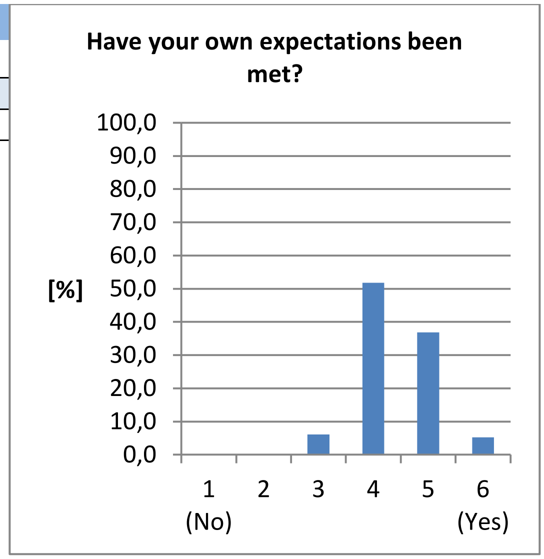


Figure 77: Results illustrating if participants expectations were met.

10. How would you rate this event overall?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	5,6 %	30,6 %	41,7 %	22,2 %

Average score:	4,6

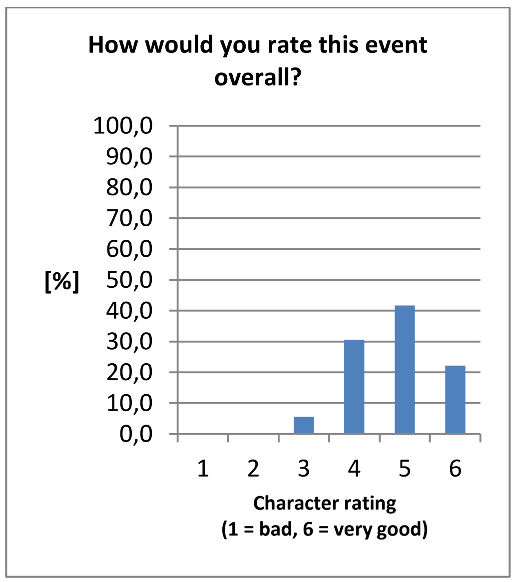


Figure 78: Results illustrating overall rating of simulator training.

King Lear training

The results from evaluation schemes from King Lear training is based on 35 participants.

King Lear drilling & well team performed training on handling of the following situations in the simulator:

1. Loss situation
2. Kick during drilling
3. Well control scenario with cross-flow

Each participant had the opportunity to respond/evaluate 10 different questions related to performed simulator training. Each question could be graded from 1-6, where 1 is the lowest score (bad) and 6 is the highest (very good). The overall results from King Lear are as follows:

1. Where the objectives clearly defined at the start?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	2,9 %	45,7 %	42,9 %	8,6 %

Average score:	4,6

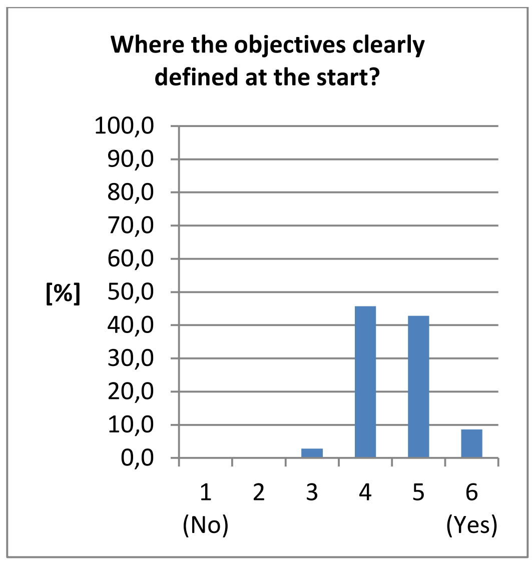


Figure 79: Results illustrating the participants' comprehension for given tasks.

2.	Was the blend of theory and exercises satisfactory?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	2,9 %	31,4 %	57,1 %	8,6 %

Average score:	4,7

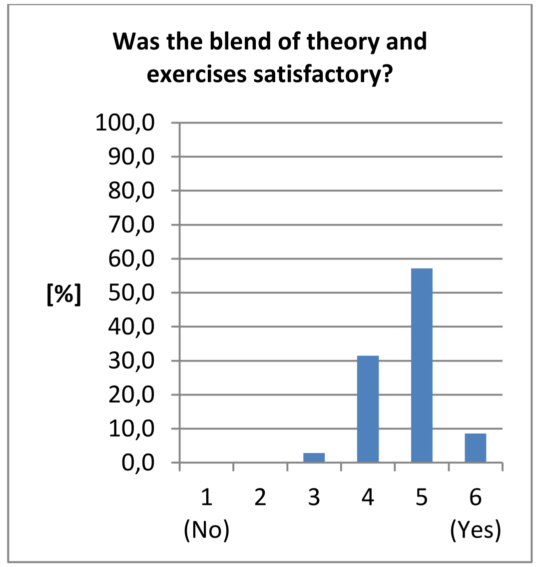


Figure 80: Results illustrating how good the blend between theory and exercises were.

3.	Do you feel that your position contributed to the team during simulator training?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	0,0 %	23,8 %	19,0 %	57,1 %

Average score:	5,3

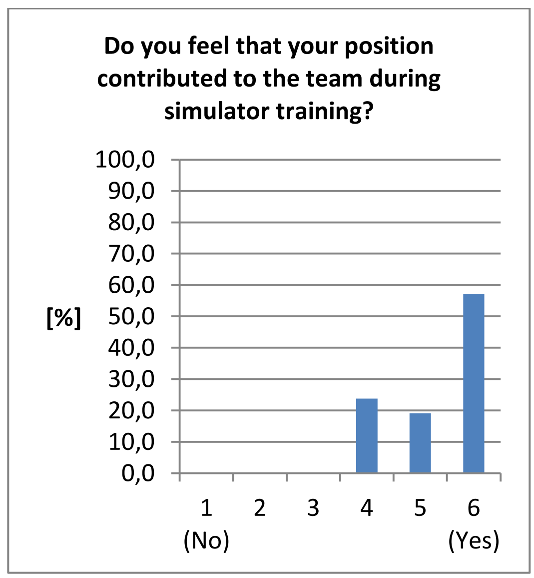


Figure 81: Results illustrating how the participants regarded her/his contribution to the team during training.

4. Would you like to be more involved?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	30,0 %	10,0 %	15,0 %	5,0 %	20,0 %	20,0 %

Average score:	4,2

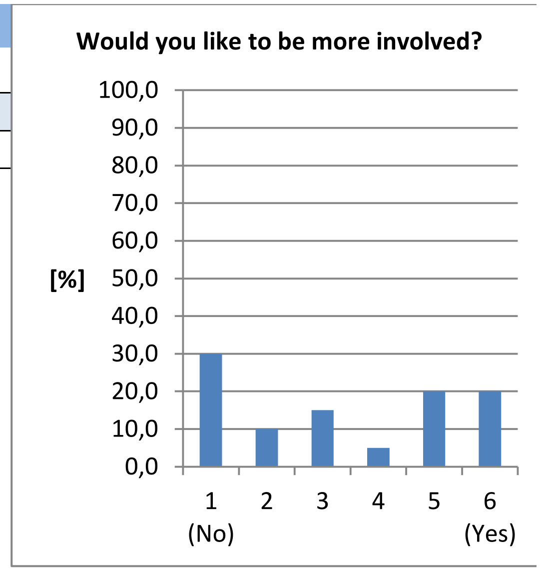


Figure 82: Results illustrates the participants` desire for more involvement in training.

5. Did the training contribute to increased understanding of well control incidents?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	0,0 %	9,5 %	57,1 %	33,3 %

Average score:	5,2

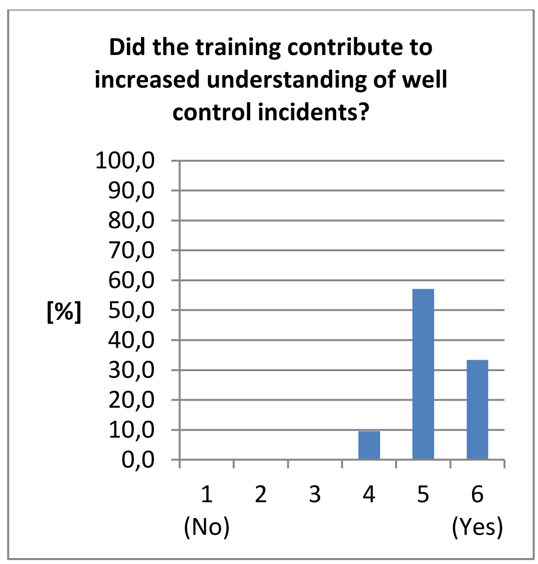


Figure 83: Results illustrating percentage of participants who experienced an increased understanding through training.

6. How will you evaluate your team`s communication and execution of given task?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	0,0 %	14,3 %	57,1 %	28,6 %

Average score:	5,1

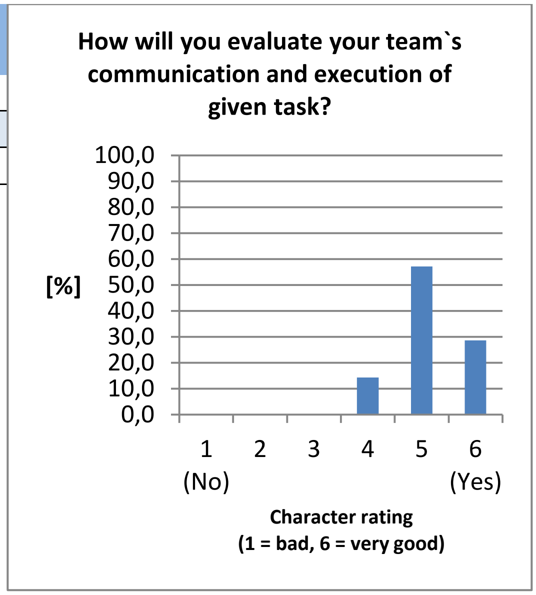


Figure 84: Results illustrating each person`s perception of the team`s communication during the exercises.

7. How many days are sufficient for simulator training?

Character	1 day	2 days	3 days
Result	50,0 %	45,5 %	4,5 %

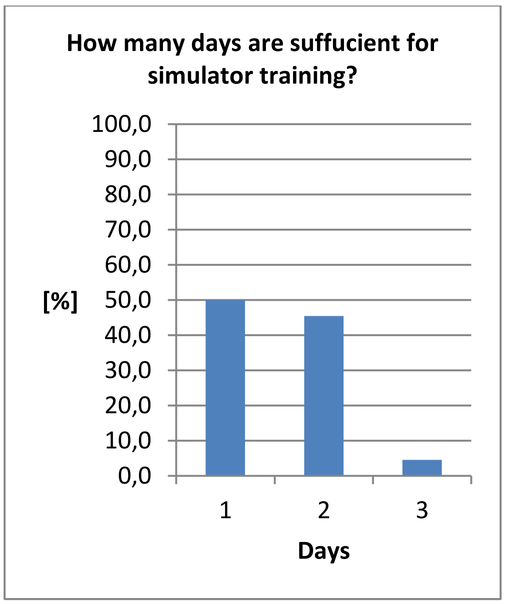


Figure 85: Results illustrating participants preferred length of simulator training.

8. Would you like to come back for training?

Character	Yes	Maybe	No
Result	100,0%	0,0 %	0,0 %

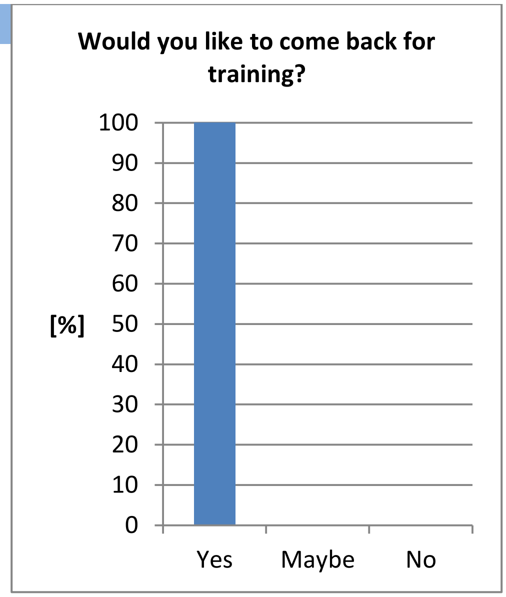


Figure 86: Results illustrating participants' desire of additional simulator training.

9. Have your own expectations been met?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	0,0 %	34,3 %	54,3 %	11,4 %

Average score:	4,8

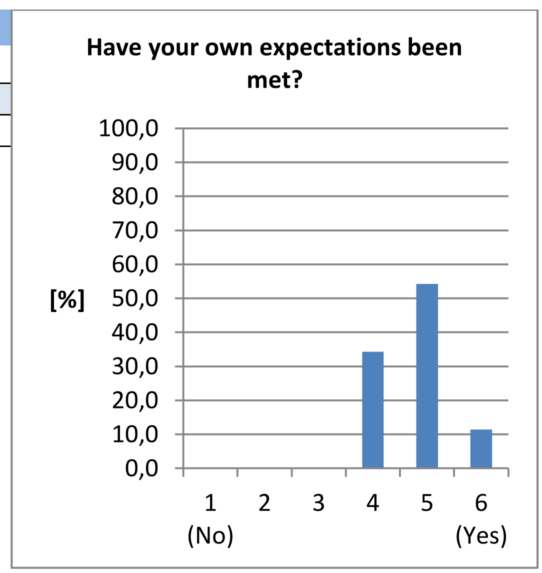


Figure 87: Results illustrating if participants expectations were met.

10. How would you rate this event overall?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	0,0 %	40,0 %	51,4 %	8,6 %

Average score:	4,7

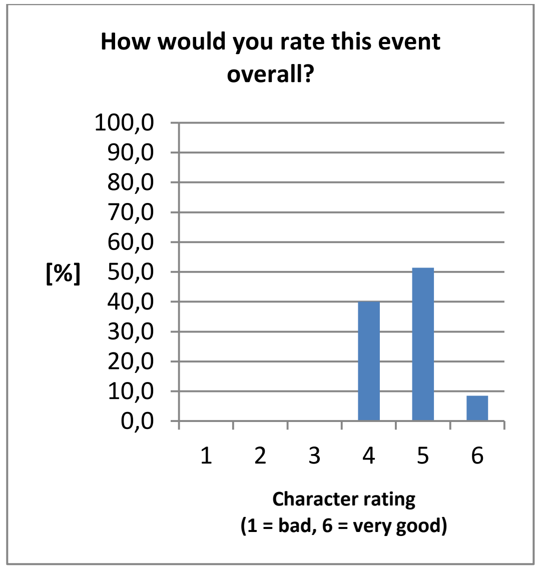


Figure 88: Results illustrating overall rating of simulator training.

Statfjord training

The results from evaluation schemes from Statfjord training is based on 59 participants.

Statfjord drilling & well team performed training on handling of the following situations in the simulator:

1. Kick scenario
2. Loss scenario leading to pack off
3. Underground blow-out

Each participant had the opportunity to respond/evaluate 10 different questions related to performed simulator training. Each question could be graded from 1-6, where 1 is the lowest score (bad) and 6 is the highest (very good). The overall results from Statfjord are as follows:

1. Where the objectives clearly defined at the start?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	11,9 %	32,2 %	45,8 %	10,2 %

Average score:	4,5

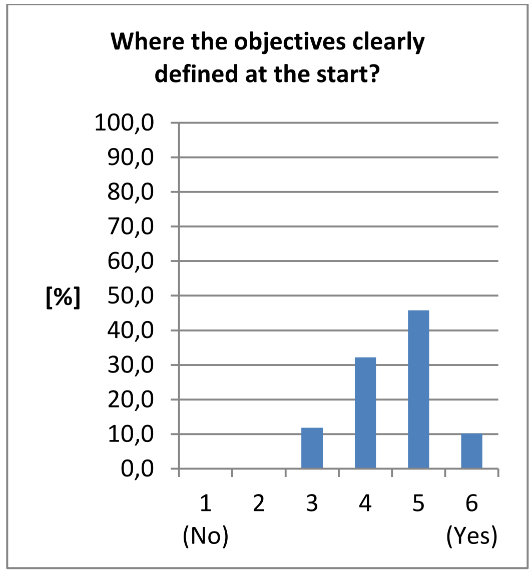


Figure 89: Results illustrating the participants' comprehension for given tasks.

2. Was the blend of theory and exercises satisfactory?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	1,7 %	3,4 %	29,3 %	44,8 %	20,7 %

Average score:	4,8

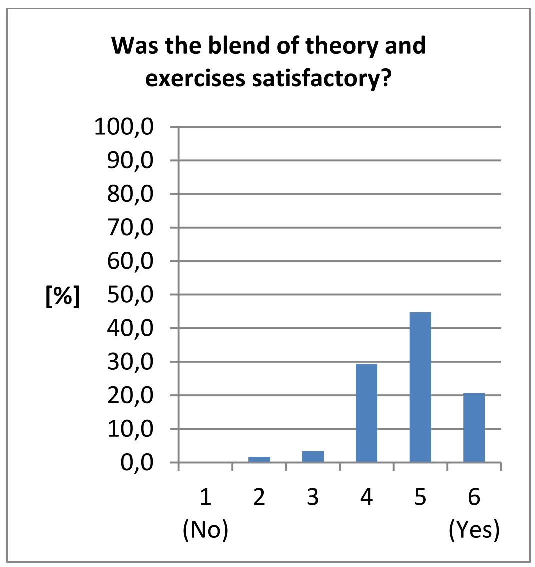


Figure 90: Results illustrating how good the blend between theory and exercises were.

3. Do you feel that your position contributed to the team during simulator training?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	5,9 %	5,9 %	11,8 %	43,1 %	33,3 %

Average score:	4,9

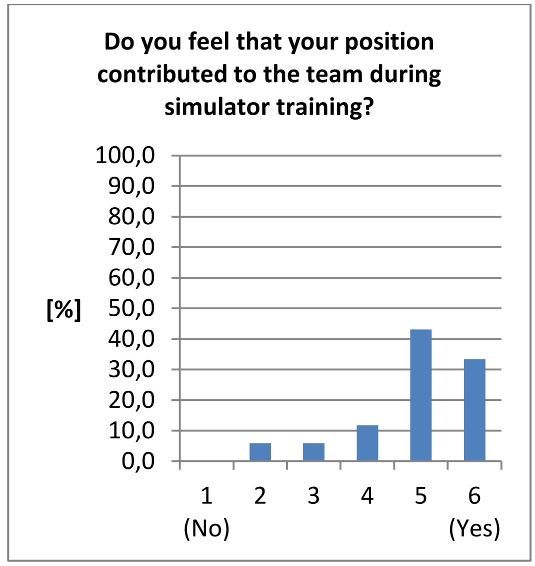


Figure 91: Results illustrating how the participants regarded her/his contribution to the team during training.

4. Would you like to be more involved?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	5,9 %	5,9 %	13,7 %	33,3 %	25,5 %	15,7 %

Average score:	4,1

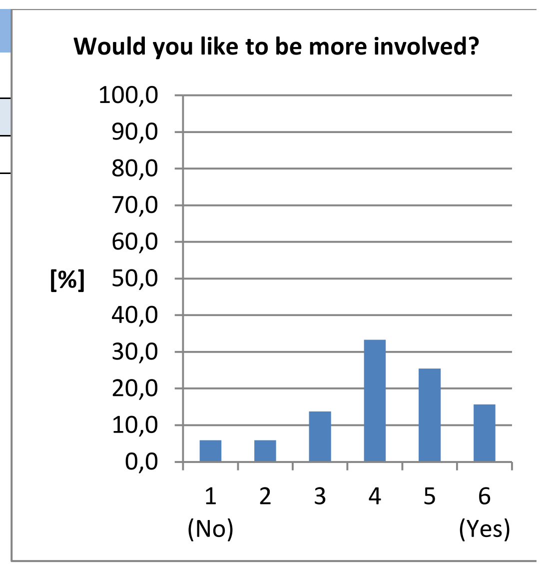


Figure 92: Results illustrates the participants` desire for more involvement in training.

5. Did the training contribute to increased understanding of well control incidents?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	2,0 %	9,8 %	21,6 %	66,7 %

Average score:	5,5

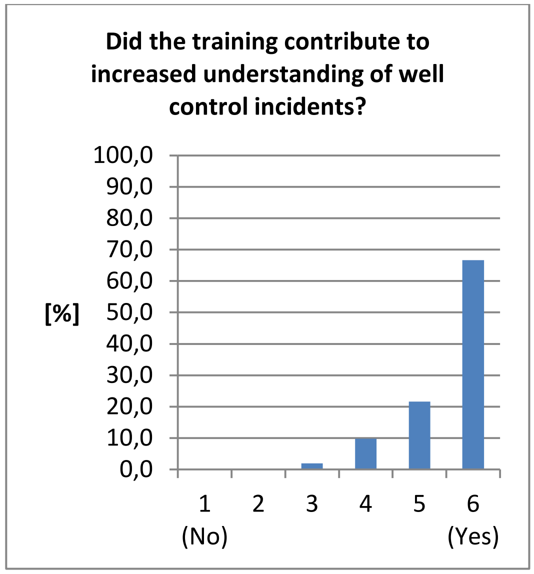


Figure 93: Results illustrating percentage of participants who experienced an increased understanding through training.

6. How will you evaluate your team`s communication and execution of given task?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	6,1%	32,7 %	49,0 %	12,2 %

Average score:	4,7

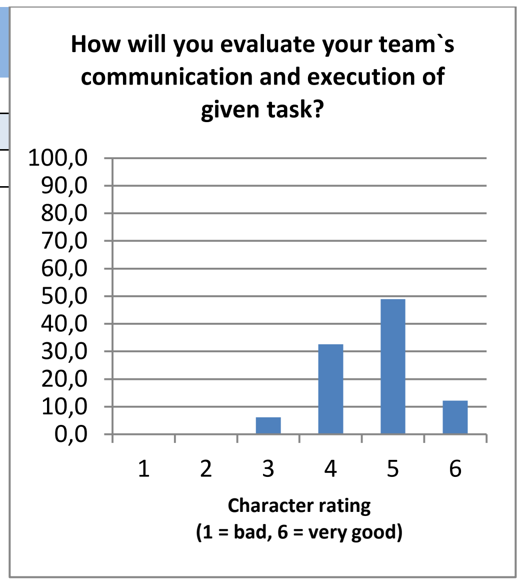


Figure 94: Results illustrating each person`s perception of the team`s communication during the exercises.

7. How many days are sufficient for simulator training?

Character	1 day	2 days	3 days
Result	46,8 %	48,9 %	4,3 %

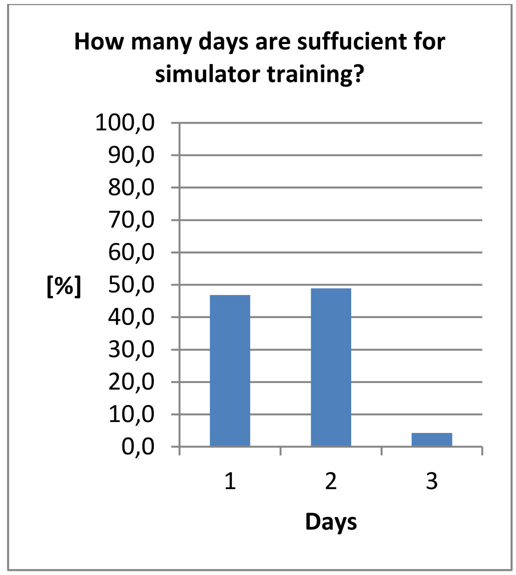


Figure 95: Results illustrating participants preferred length of simulator training.

8. Would you like to come back for training?

Character	Yes	Maybe	No
Result	100,0%	0,0 %	0,0 %

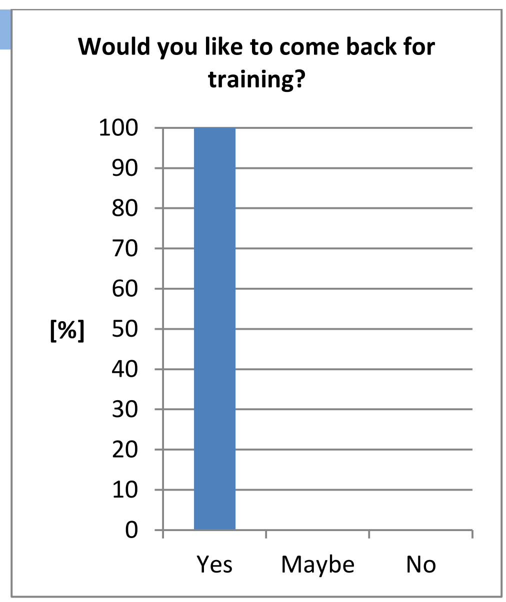


Figure 96: Results illustrating participants' desire of additional simulator training.

9. Have your own expectations been met?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	1,7 %	23,7 %	54,2 %	20,3 %

Average score:	4,9

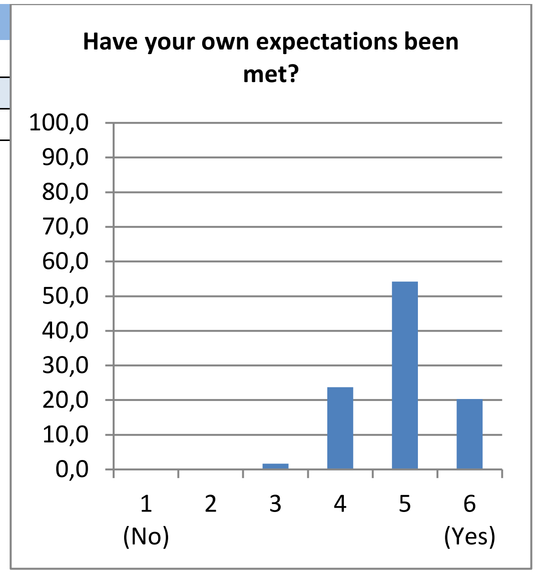


Figure 97: Results illustrating if participants expectations were met.

10. How would you rate this event overall?

Character	1 (No)	2	3	4	5	6 (Yes)
Result	0,0 %	0,0 %	0,0 %	22,0 %	57,6 %	20,3 %

Average score:	5,0

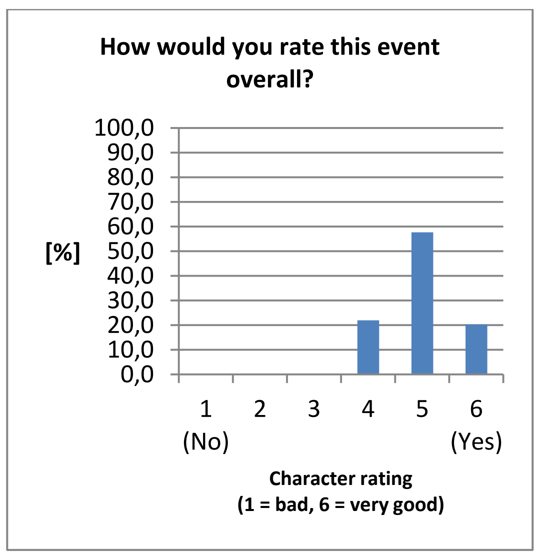


Figure 98: Results illustrating overall rating of simulator training.