University of
Stavanger

**Faculty of Science and Technology**

# MASTER’S THESIS

Study program/ Specialization:

Petroleum Engineering/Drilling Engineering

Spring semester, 2011

Restricted Access

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Title of thesis:

## Mainbore Connectivity in Perforated Whipstock Multilateral Wells

Credits (ECTS): 30

Key words:

Mainbore and Lateral
Starburst Multilateral
TAML
Hollow Whipstock
Milling
Perforation

Pages: 52

+ enclosure: 5

Stavanger, June, 2011

# Mainbore Connectivity in Perforated Whipstock Multilateral Wells

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*June 15, 2011.*

University of
Stavanger

## Acknowledgement

*The Journey to completing my master’s degree at the University of Stavanger ends with this thesis and it is with great delight that I acknowledge those who have contributed immensely to the success of this thesis.*

*Firstly, I am highly indebted to my Supervisors* ***Claas van der Zwaag*** *(Statoil ASA and University of Stavanger) and* ***Frode Berge*** *(Statoil ASA) for giving me the opportunity to work on this exciting thesis. Their immense support and guidance throughout the thesis is highly appreciated especially their open door policy to me, as I was welcomed whenever I needed a chat and they were always very happy and willing to direct me towards the next step.*

*I wish to also express my appreciation to the* ***management and staff of the Drilling and Well technology-Drilling Technology department at Statoil ASA*** *for their contribution in granting me access to information need from the company for the thesis.*

*I will not end this section without thanking my family and friends for their support and encouragement*

*Above all, I thank the Almighty God for His grace, wisdom, favour, faithfulness and protection.*

*With regards,*
*Rumi Anthony Achije*

*Stavanger, June 15, 2011*

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# Abbreviations

| | |
|---|---|
| ***RIH*** | *Run in Hole* |
| ***MU*** | *Make up* |
| ***BU*** | *Bottoms Up* |
| ***POOH*** | *Pull out of hole* |
| ***LD*** | *Lay down* |
| ***lpm*** | *Pounds per minute* |
| ***MW*** | *Mud weight* |
| ***DC*** | *drill collar* |
| ***HWDP*** | *Heavy weight drill pipe* |
| ***DP*** | *Drill pipe* |
| ***MD*** | *measured depth* |
| ***TVD*** | *True vertical depth* |
| ***LSOBM*** | *Low solid oil base mud* |
| ***OBM*** | *Oil base mud* |
| ***WBM*** | *Water base mud* |
| ***WOB*** | *Weight on bit* |
| ***HEC*** | *hydroxylethyl cellulose* |
| ***sg*** | *Specific gravity* |
| ***rpm*** | *revolution per minute* |
| ***GR*** | *Gamma Ray* |
| ***RA*** | *Radioactive* |
| ***HC*** | *Hydrocarbon* |
| ***TCP*** | *Tubing conveyed perforation* |
| ***BHA*** | *Bottom hole Assembly* |
| ***DHSV*** | *Down Hole safety valve* |
| ***RSS*** | *Rotary steerable system* |
| ***TAML*** | *Technological advancement of multilateral* |
| ***SAQC*** | *Shallow angle quick cut* |
| ***Ft lbs*** | *foot pounds* |
| ***TSP*** | *TAM straddle packer* |

# Abstract

The Starburst Multilateral is a special type of the TAML level 4 junction built around the proven concept of the hollow technology. This hollow technology has been in use in the North Sea for the past ten years and there have been significant improvements in this tool allowing for high pressure capability before and after milling the window. An innovative concave geometry protects the concave face during milling operation and after drilling the lateral, the liner is installed and cemented across the junction before the hollow whipstock and liner is perforated to regain production.

As of date, most of Statoil wells in the Gullfaks area are in their latter stages of production, since the Gullfaks field is a typical mature field. This has led to the challenges of wells producing at low rates; however these rates are not lower that what can be delivered by an alternative use of the slot. Thus one solution to these challenges is employing the Starburst multilateral technology to maintain production from the old well while gaining inexpensive access to new drainage points.

This thesis describes the Starburst multilateral technology and the special tools used for it's installation at various Statoil wells in the North Sea, with details on challenges with connectivity at the junction after perforation of whipstock, concluding with significant findings, discussion and possible solution to the challenges.

# 1 Introduction

As multilateral junction equipment and systems begin to evolve, there was an increasing need to group these multilateral systems industry- wide based on level of functionality at the junction. To be operationally feasible a multilateral would have to provide the following [1]

1. Capability to sidetrack to one of a number of previously identified locations immediately after logging.
2. Capability to maintain the original wellbore for production access.
3. Capability to maintain the lateral wellbore without adding associated access risks to the lateral wellbore
4. Applicability to older wells that could be side tracked, yet maintains the original mother bore's production without introducing any access risks to the lateral.

An elaborate naming convention was developed by the consortium group: Technology Advancement of MultiLaterals (TAML), which is based on functionality level, flow control, lift mechanism and re-entry capabilities.[1, 2] There are essentially six functionality levels that are commonly used to describe all multilateral junctions these are discussed below[3]

Level 1, A multilateral junction with an openhole lateral from an openhole mother bore and requires no mechanical or hydraulic junction. Thus they are usually carried out in consolidated formations as barefoot completions.

Level 2, A multilateral junction in which mainbore is cased and cemented with the lateral open. The completion is economical, allows selective production and can be carried out in standard casing sizes.

Level 3, A multilateral junction where mainbore is cased and cemented and lateral bore is cased but not cemented, screen, slotted pipe or liner is placed in the open hole and tied back to the main bore

Level 4, A multilateral junction in which both the lateral and mainbore are cased and cemented to provide mechanical junction integrity, these system can be simple, or they can be the basis for more complex systems.

Level 5, A multilateral junction where both the lateral and the mainbore are usually cased and cemented and the junction is hydraulically isolated using completion equipment to prevent junction collapse due to drawdown.

Level 6, A multilateral junction where the completion system used for this application achieves junction pressure integrity with casing and is developed to address needs raised through use of level 5 system, mostly notable

- Elimination of debris
- Risk reduction
- Simpler installation
- Top-down construction

The figure below shows the classification of the multilateral wells according to the TAML system.

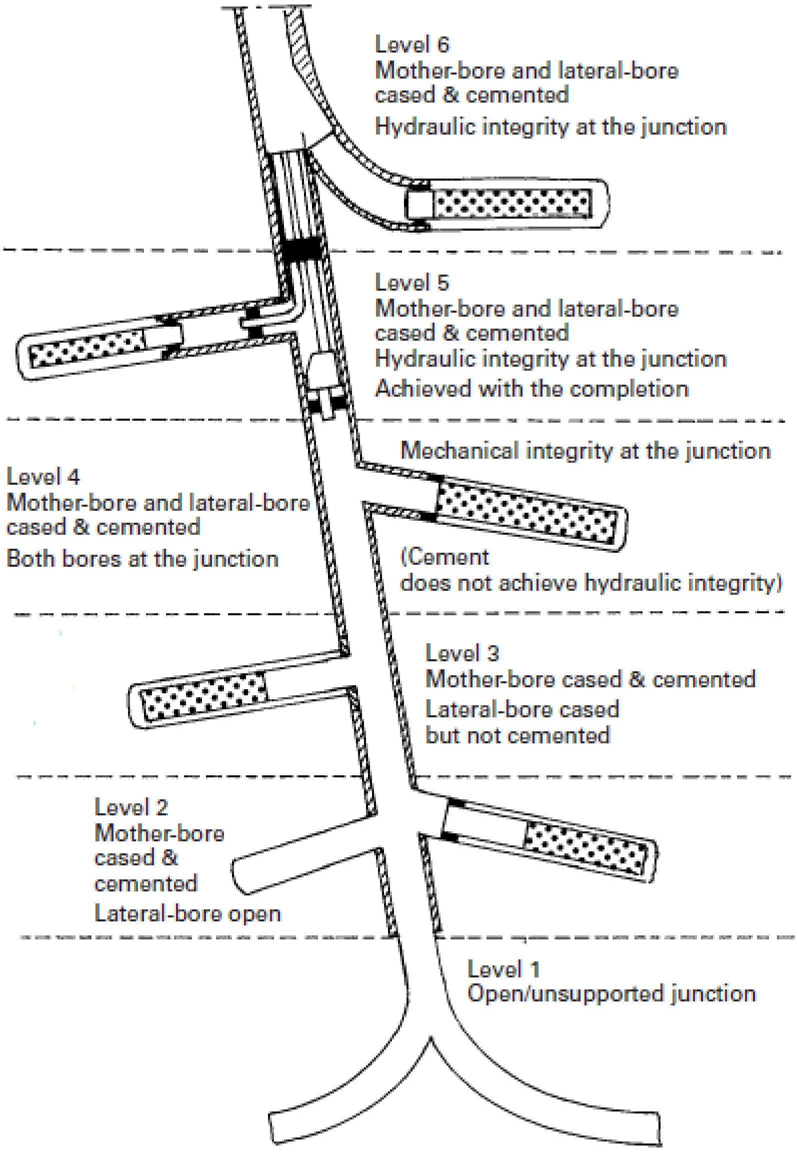


**Figure 1; showing Multilateral wells classification (TAML)**

## 1.1 Study Objective:

This work will focus mainly on a special kind of TAML 4: StarBurst™ designed by Weatherford International and a possible way of tackling the challenges faced in the running and installation of the tools at some of the fields operated by Statoil.

The wells used for this work are from the Gullfaks field which is located on the Norwegian Continental Shelf.

## *1.2 Background of Fields*

The Gullfaks shown on figure 2 is a typical mature field and has produced since 1986. It has been developed with three concrete integrated production and drilling platform; namely the Gullfaks A, B and C. The total production rate from the Gullfaks field is currently some 26 000Sm$^3$/d with estimated total recoverable reserves of 360 million Sm$^3$[4]. Gullfaks is a typical mature field where cost efficient solutions need to be in focus as well as the challenge that old wells produce at low rate. One solution to this challenge is to maintain production from the old well while simultaneously gaining inexpensive access to new drainage point (s).

The Oseberg Field Centre shown on figure 3, like the Gullfaks is also a mature field that has been in operation since 1988 and consist three platforms, Oseberg A, B and D connected to one another with bridges in the southern part of the Oseberg field, and the Oseberg C platform, which lies some 14 kilometres north of the field centre. [5]

The Åsgard field is a subsea development incorporating three fields, Smørbukk, Smørbukk Sør, and Midgard. This area of the Norwegian Sea experiences very unpredictable and extreme weather conditions presenting major challenges to both equipment and personnel. Prospect development is well advanced, with only a few slots remaining in the subsea templates for new well development thus new well are more cost effective if a multilateral well is used that increases the drainage points in the reservoir.[6]

The cost to drill a new well compared to using multilateral technology in an existing well can be substantial. In spite of this, the time required to drill a lateral compare to drilling an entire new well is substantially less. This, combined with reduction in equipment, supplies and service requirements make the drilling of lateral from an existing well support this goal.

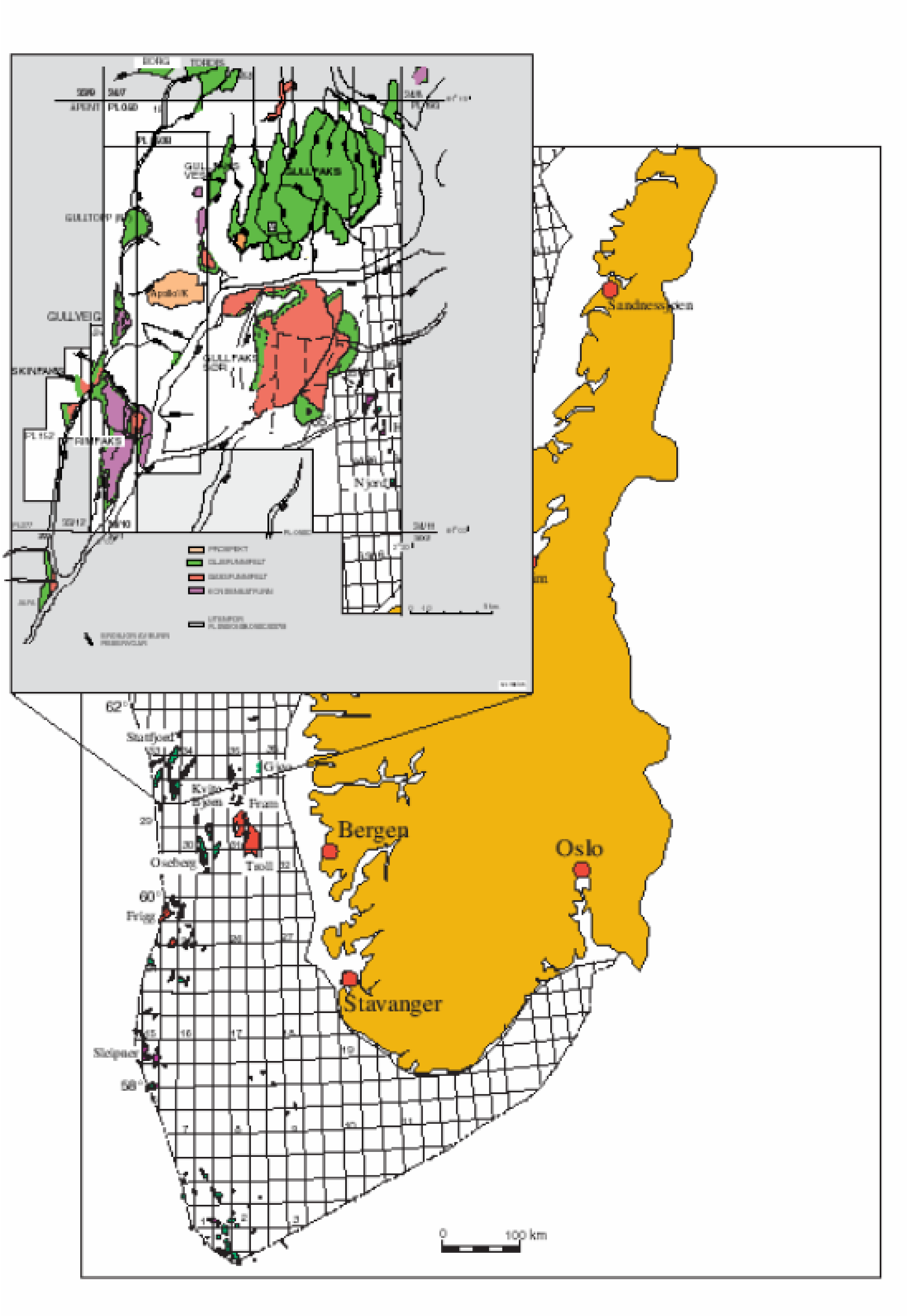


Figure 2; Location of the Gullfaks field

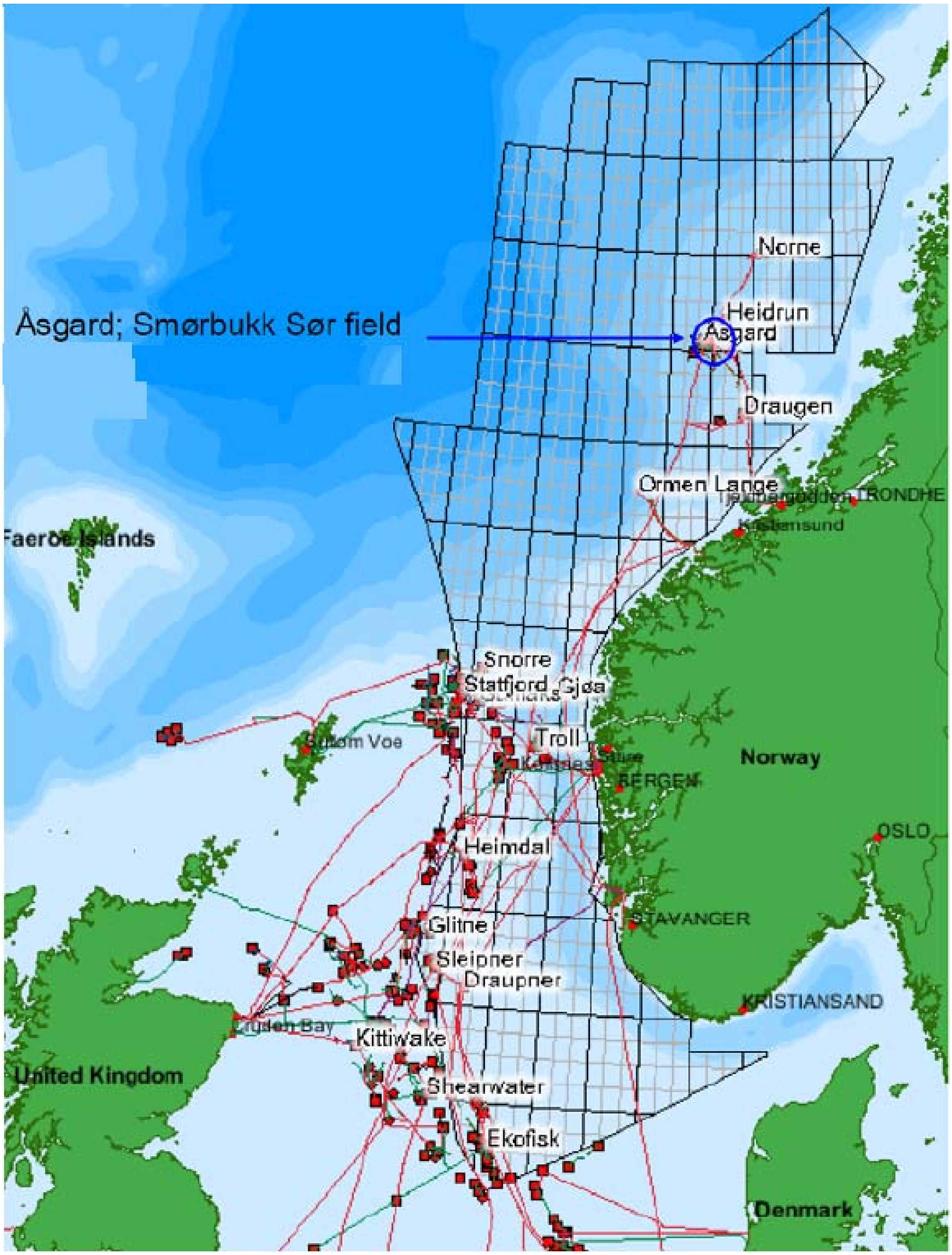


Figure 3; Location of Åsgard field

# 2 Description of Tool Components

The Weatherford's OneTrip Starburst™ multilateral system creates a level 4 cemented junction with the full-liner access to the lateral bore, the system incorporates a QuickCut milling system for orientation of the whipstock-anchor assembly, milling of window, and drilling of the rathole in a single run. The multipurpose whipstock is used in the milling, drilling and completion phases.[7]

After the window is milled and the lateral is drilled, a conventional lateral liner assembly is run into the lateral and anchored back to the mainbore above the window. Once the liner is run, it is cemented. Perforation of the OneTrip Starburst hollow whipstock and the liner at the junction is accomplished by the special StarBurst perforating gun, which uses a controlled-depth charge to maintain junction integrity

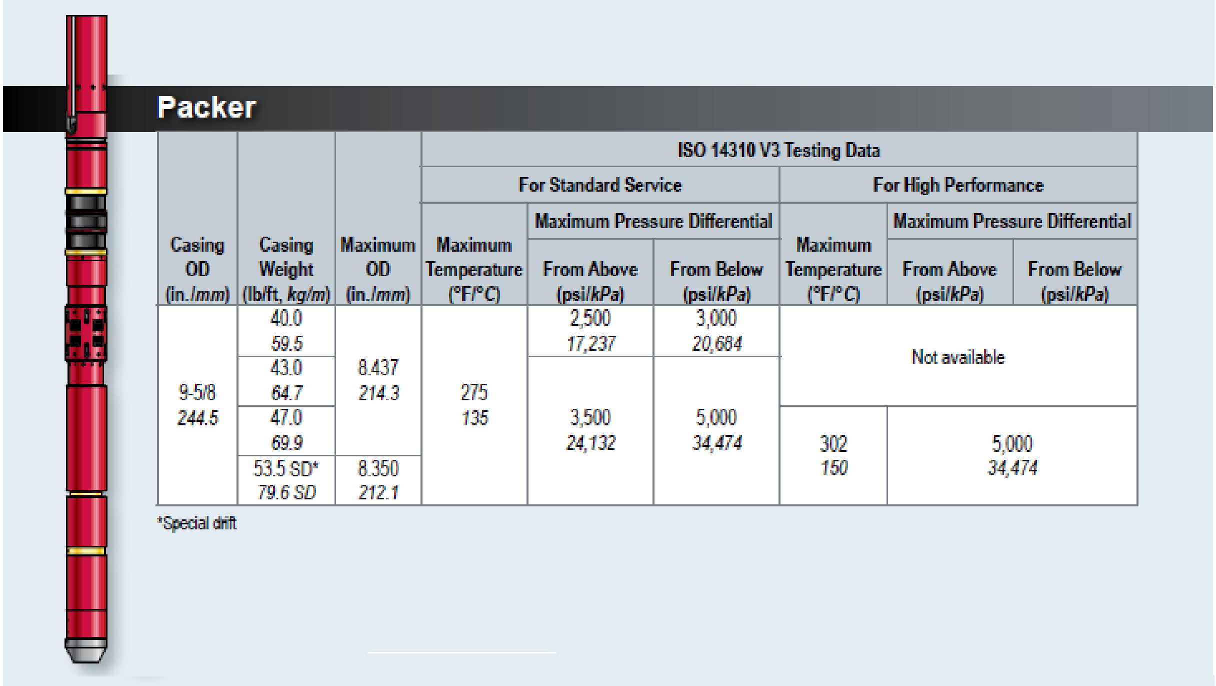
## *2.1 The Timer Plug:*

The sole purpose of this device is to provide hydraulic isolation of the motherbore until the whipstock could be put in place. Subsequently it should open up for hydraulic communication and ideally not cause a pressure restriction in the wellbore.[8]

Several tests were performed on this plug, and the final test being performed in Gullfaks B-1 where a plug was installed some weeks before the sidetrack operations and set to open in 48 hours. This opening was observed as planned and a pressure drop of approximately 5 bars measured across the device

## *2.2 The Whipstock Anchor;*

Several options were considered when deciding the base support to choose for the TAML 4 Starburst system. The final decision was based on a 10,000ft-lbs torque requirement by most operators while allowing hydrocarbon to be produced through the inner bore[9]. This Packer-like tool shown on figure 4 is another device with similar function as that of the timer plug describe above, it basically enables the use of heavier drilling mud without damaging the reservoir because it acts as a  seal to isolate the main bore during the lateral drilling, it can be designed to be retrievable, which expedites remediation and contributes to downhole flexibility. It Internal diameter (ID) allows oil and gas to flow through the tool after perforation of the whipstock. It can be run and if necessary, retrieved on the same run as the whipstock thus saving time. Its is well suited for harsh drilling environments



**Packer**

| | | | ISO 14310 V3 Testing Data | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | For Standard Service | | | For High Performance | | |
| | | | | Maximum Pressure Differential | | | Maximum Pressure Differential | |
| Casing OD (in./*mm*) | Casing Weight (lb/ft, *kg/m*) | Maximum OD (in./*mm*) | Maximum Temperature (°F/°C) | From Above (psi/*kPa*) | From Below (psi/*kPa*) | Maximum Temperature (°F/°C) | From Above (psi/*kPa*) | From Below (psi/*kPa*) |
| 9-5/8<br>*244.5* | 40.0<br>*59.5* | 8.437<br>*214.3* | 275<br>*135* | 2,500<br>*17,237* | 3,000<br>*20,684* | Not available | | |
| | 43.0<br>*64.7* | | | 3,500<br>*24,132* | 5,000<br>*34,474* | | | |
| | 47.0<br>*69.9* | | | | | 302<br>*150* | 5,000<br>*34,474* | |
| | 53.5 SD*<br>*79.6 SD* | 8.350<br>*212.1* | | | | | | |

*Special drift

**Figure 4; packer assembly courtesy weatherford**

## 2.3 The Milling system:

A lot of emphasis is placed in the design of this system to minimise risk during the formation of the window at the junction. This is usually carried out in two trips but with the new milling tool; shallow-angle QuickCut (SAQC)™ this can be done in a single trip.[7]

The first is usually a tri-bladed starter mill run, followed by a multilateral window mill- run that will complete the window, the preliminary mill is a tri-bladed starter mill that cuts out above the top of the whipstock and elongates the window to provide a long exit from the mainbore to the lateral. This is important because the longer window when complete will facilitate better transition of stiff drilling and completion. The multilateral window mill has an extended gauge section and a tapered face design to ensure that the whipstock is not damaged during milling operations.

With the shallow-angle QuickCut (SAQC) the tool is designed in such as way that it can orient, anchor and mill a long window and deep rathole in a single trip allowing the use of a rotary- steerable assemblies to drill the lateral thus reducing the rig time and subsequently cost

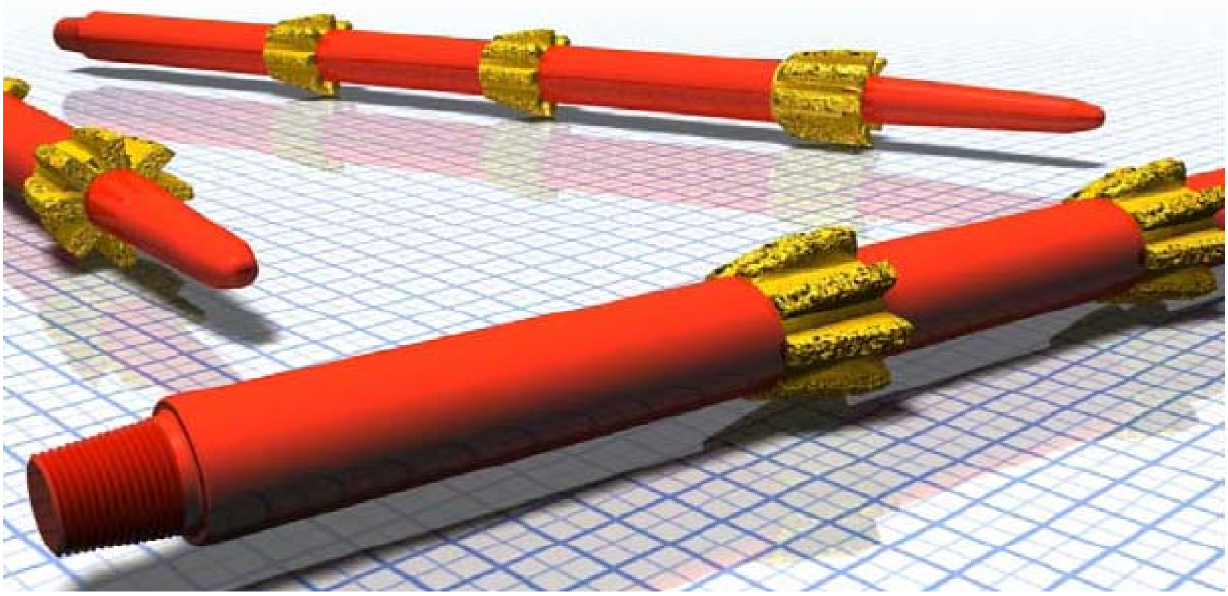


**Figure 5; Tri bladed starter mill**

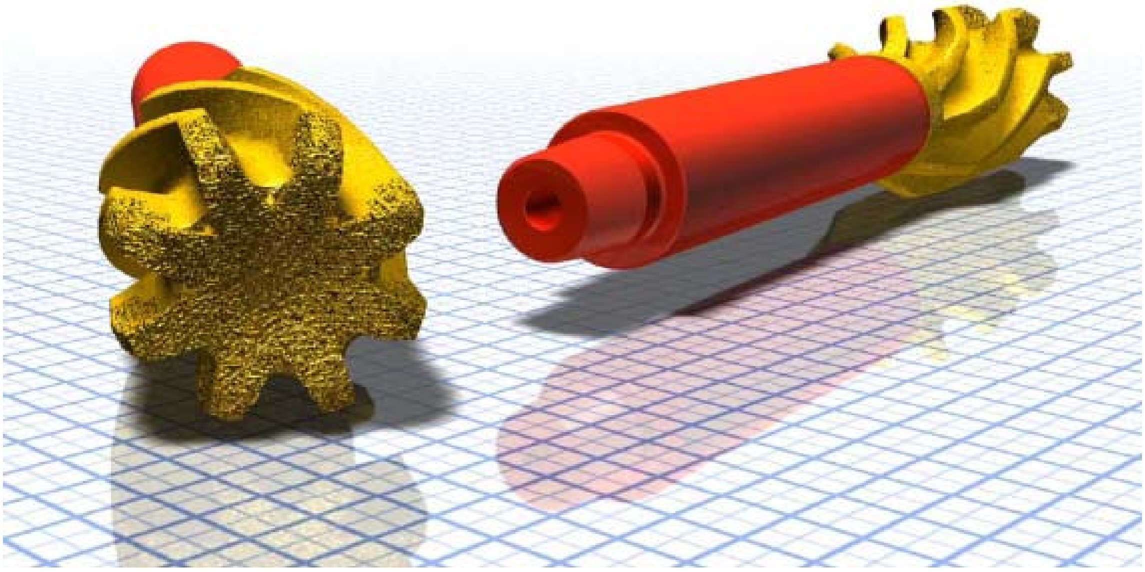


**Figure 6; Multilateral window mill**

## 2.4 The Hollow Whipstock

In order for this tool to perform the designed functions then it must meet the following requirements[7]

- Allow the milling system to exit the casing above the top of the whipstock to create a long window.
- Ensure the milling system does not damage the pressure integrity of the barrier and perforation plate.
- holds sufficient differential pressure to maintain junction integrity during the drilling operations
- Contain an area which can be easily and reliably perforated in a controlled manner.
- Allow flow of hydrocarbon or injection fluid through these perforations to support economical development of the well.

The whipstock assembly consist of a hollow whipstock with a perforation plate which has about 3-degree angle on the plate and usually pressure tested to about 340bars in collapse and burst. The Whipstock also includes a kick-over device to ensure that the tip of the whipstock lies on the low side of the casing. Without such a device, it is probable that the whipstock would remain centred in the well, with the tip of the whipstock slightly off the low side of the casing, mainly due to the perforation system that needs to lie on the low side of casing. Below is a diagram showing the parts that make up the whipstock assembly

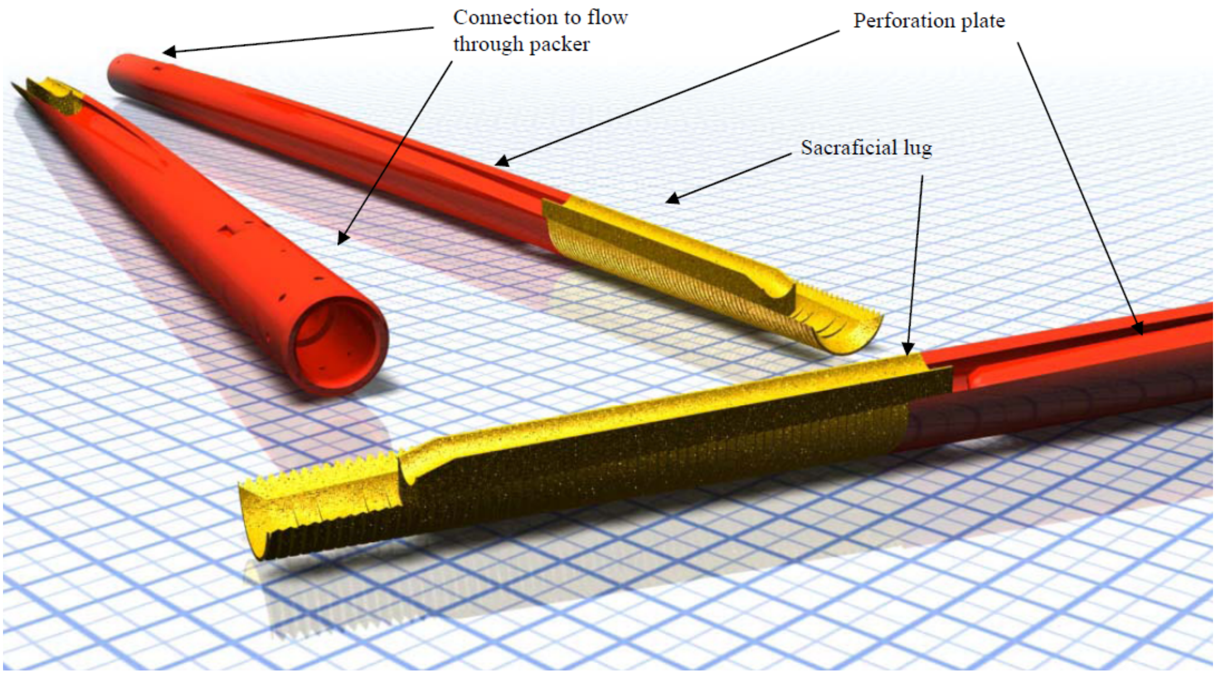


**Figure 7; Hollow Whipstock assembly**

## 2.5 The Perforation System;

In order to ensure flow of fluid during production from the mainbore as well as lateral to the surface, then the junction needs to be perforated. This requires special charges design to produce relatively short, but large diameter charges. These charges are designed in such a way that they can penetrate the liner, cement between the liner and the perforation faceplate. In all the total amount of penetration required from this system is just about 4.1 inches in the worst cases.

The diameter of the holes at the back of the perforation plate, or total flow area, greatly affects the pressure drop and will also determine the sustainability of the junction for some mature wells. The equation below shows how the total flow area is critical in making this type of junction successful.

$$\Delta P = \frac{MW \times Q^2}{12301 \times TFA^2 \times Cd^2} [10]$$

MW = mud weight (lbs/gal)

Q = flow rate (gpm)

TFA = total flow area (in²)

CD = discharge Coefficient

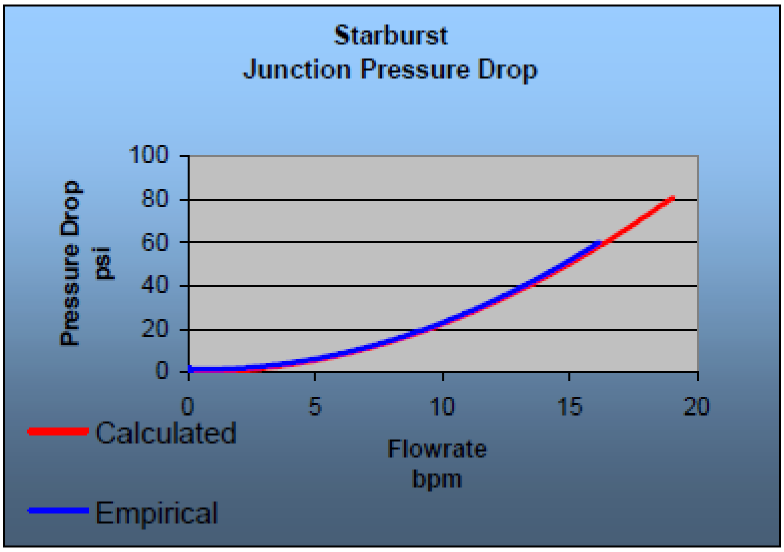
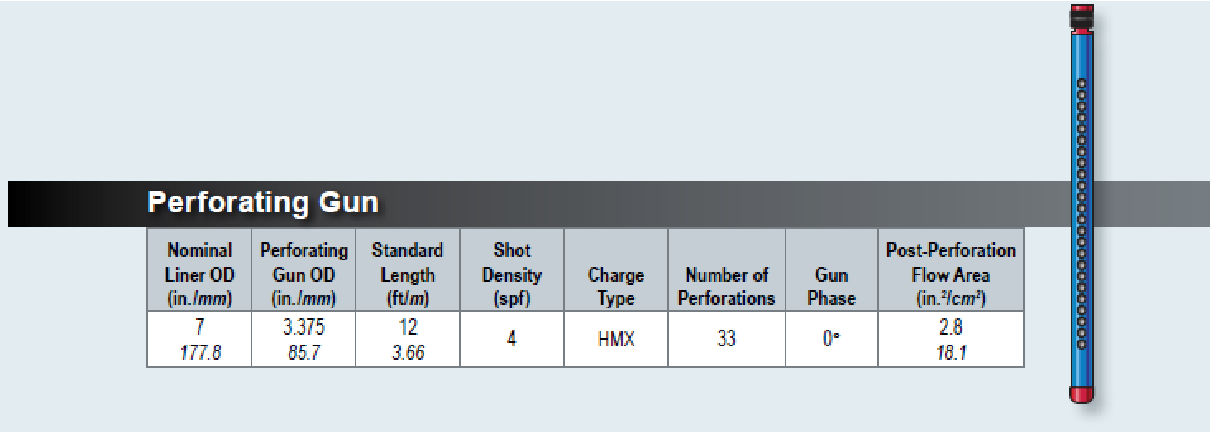


**Figure 8; pressure drop vs flowrate through perforated whipstock**

From this equation one can clearly see in figure 8 that increasing the average hole size created by the perforation will greatly increase the performance of this junction. The perforation need to be designed as not to degrade the integrity of the casing at the junction, by shooting through the casing string.

The charges are located with RA tags placed in the whipstock at both the top and bottom. These whipstock RA tags will allow for the proper and consistent placement of the perforation guns.[11]



**Perforating Gun**

| Nominal Liner OD (in./*mm*) | Perforating Gun OD (in./*mm*) | Standard Length (ft/*m*) | Shot Density (spf) | Charge Type | Number of Perforations | Gun Phase | Post-Perforation Flow Area (in.²/*cm²*) |
|---|---|---|---|---|---|---|---|
| 7<br>*177.8* | 3.375<br>*85.7* | 12<br>*3.66* | 4 | HMX | 33 | 0° | 2.8<br>*18.1* |

Figure 9; Perforation gun

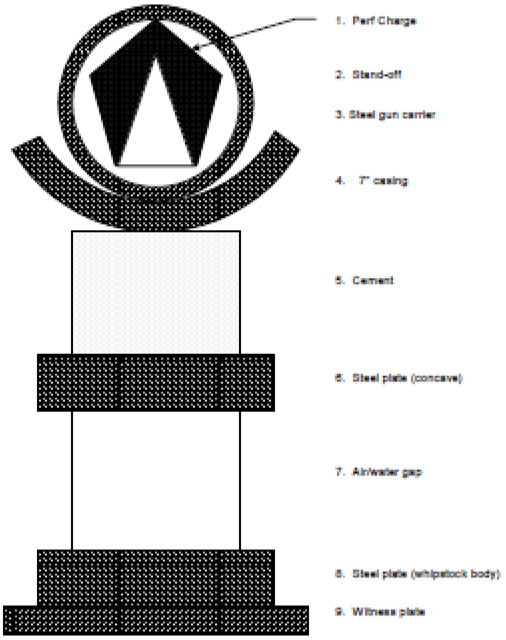


Figure 10; Perforation coupon setup

# 3 Whipstock Installation Process

## 3.1 Preparing the Well ;

A gauge cutter is run to remove debris in the wellbore and work string ensuring that the packer and the whipstock assembly can move freely along the wellbore to the setting depth, prior to running the whipstock and the eventual sidetracking operations, the existing perforations would need to be isolated and the old completion string pulled. Isolation of the old perforation is usually achieved using a timer controlled device designed to safely isolate the perforation until the whipstock is run in place and tested

**Figure 11; Gauge run**

### 3.2 Running Whipstock;

The hollow whipstock and packer is run on the milling assembly. This assembly is RIH at a steady state, similar to procedure for running the conventional whipstock. Once the setting depth is reached, the control valve controls the flow of fluid to the packer system and the MWD tool, thus allowing for circulation through the MWD tool in order to align the system assembly in the hole. Once orientation is achieved, the control valve is indexed to stop the flow to the annulus and pressure thereby directed to the hydraulic setting chamber in the packer, The MWD tool is used to check the orientation after setting and following successful readings, the running tool assembly was sheared upwards from the whipstock and tripped out of hole.

**Figure 12; Running whipstock and packer**

### 3.3 Milling Window and rathole;

A tri-bladed, cone tripped starter mill is used to create the initial portion of the junction window. The cone of the mill tags the sacrificial brass lug which forces the mill into the top of the casing, while protecting the hollow whipstock at the same time. On completion of the milling, the window is reamed to ensure a smooth, full-gauge exit hole after which the milling BHA is pulled out of the hole

**Figure 13; Milling window and rathole**

## 3.4 Drilling Lateral;

after milling the window, the drilling assembly - a rotary-steerable system (RSS) or drilling motor- is run and used to drill the lateral further, to avoid unnecessary wear and strain on the whipstock face plate, procedures are put in place during the drilling phase to ensure that the string is always oriented to the high side while tripping past the whipstock. In addition rotation is not allowed when BHA components are located across the whipstock. The single-angle concave of the whipstock enables a smooth transition from the mainbore into the lateral section, facilitating the use of longer RSSs to drill long, step-out wells. The multilateral junction can be perforated immediately, depending on the drilling objectives

**Figure 14; drilling lateral with RSS**

### 3.5 Running and cementing lateral Liner:

Installation of the lateral liner is done by anchoring it to the mainbore above the window with conventional liner hanger system and then a standard cement job is performed to hold the liner in place and this also gives mechanical support at the junction and then the lateral is perforated and the necessary sand control and completion practises are carried out. This resulting overlapping concentric casing strings combined with the cement, ensures a TAML level 4 multilateral junction with maximum borehole support throughout the life of the well

**Figure 15; installation, cementing and Perforation of lateral liner**

### 3.6 Perforation of whipstock:

Perforation of the hollow whipstock is done to re-establish production from the mainbore below the junction, using a zero-phase perforating gun with charges specifically designed to provide maximum flow area through the hollow concave plate. Perforating operations can occur immediately after the lateral bore completion or, if preferred, can be conducted later in the life of the well. Perforating can be done on either wireline or tubing as show in the figure to the right providing maximum flexibility to the operator. Radioactive tags implanted on the whipstock facilitate accurate depth correlation during the perforation process.

**Figure 16; showing perforation done on wireline and tubing**

## 3.7 Completing the well and commencing production;

The final stages of this procedure is completing the well and thereby commencing production from the mainbore and/or lateral wellbore. A wide variety of completion systems including intelligent completion by the use of ICVs Inflow control valves and other options are available and this can allow for either commingled or isolated production or flow control from both the primary and lateral wells.

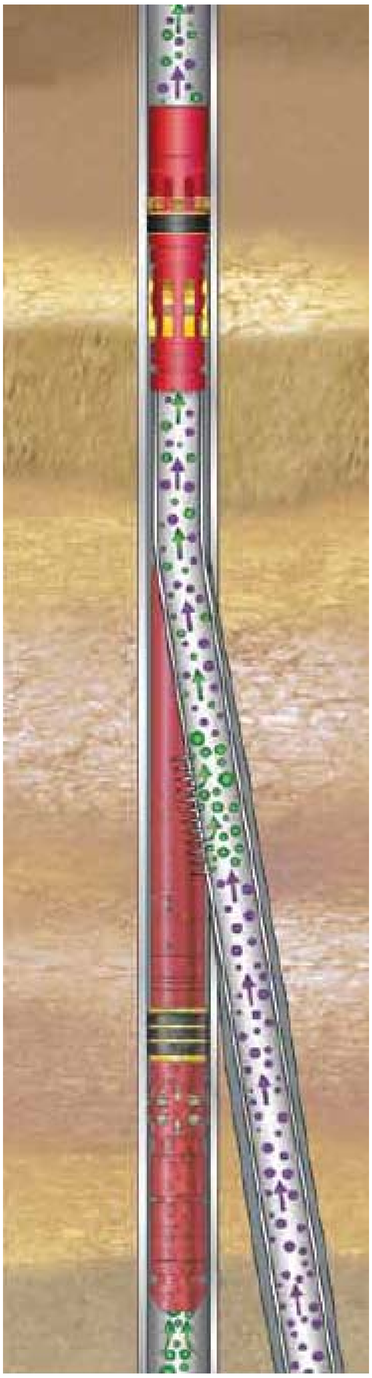


**Figure 17; showing production of fluid after completion**

# 4 Field cases and Studies

From the period of 2002 to 2011, there have been a total of 12 Starburst Multilateral installations in Statoil with most of them installed in the Gullfaks field, so far 3 of these junctions have not be perforated till date leaving 9 of them perforated, but 4 of the 9 perforated junctions have shown no sign of mainbore communication.

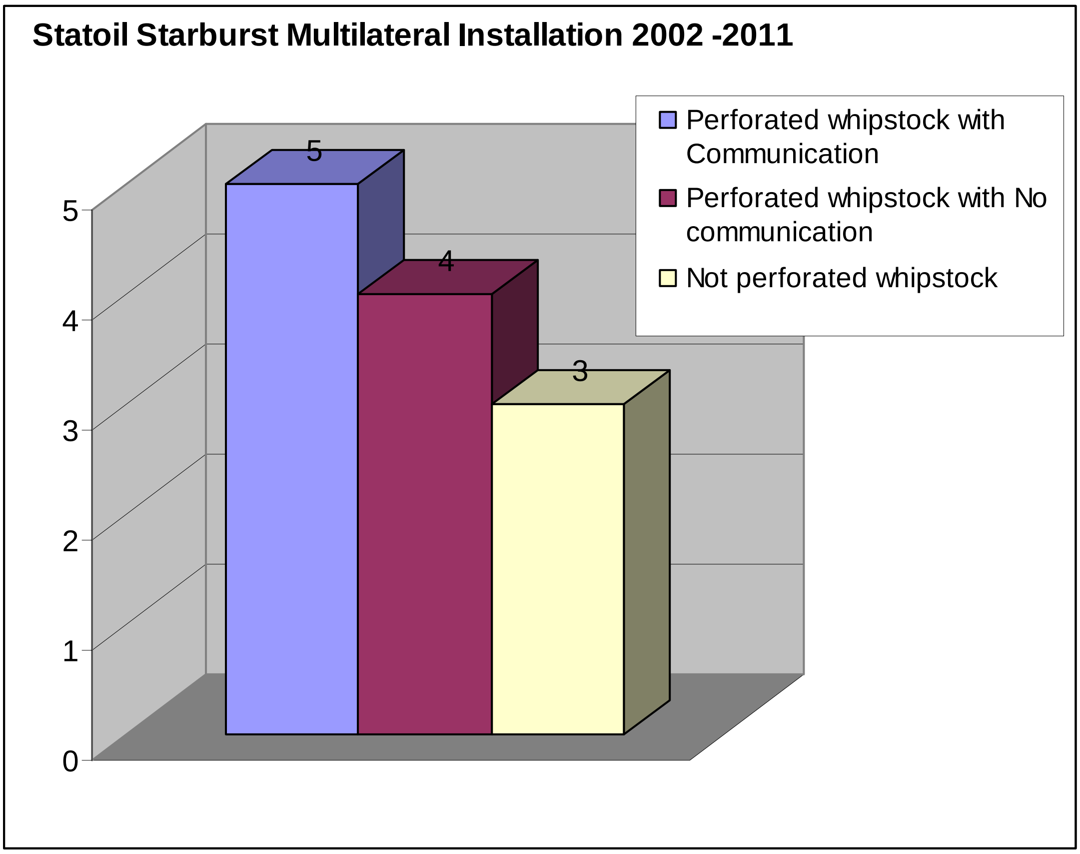


**Figure 18; showing statoil starburst installtion from 2002-2011**

The idea here is to go through some of these wells looking carefully into the following:

- Operational sequence just before running whipstock
- kind of mud and mud properties in Mainbore during running of the whipstock
- type of completion in mainbore and lateral, as well as perforation strategy
- orientation of the whipstock
- centralisation of the liner past the starburst
- cementing between the liner and starburst

Due to the agreement on confidentiality between Statoil and the University of Stavanger, a fictitious slot name is used in the description below.

## *4.1 Gullfaks Well 1*

This well was drilled from the Gullfaks platform as a production well, Since this is a mature field and also due to the declining nature of production from the field, decisions were taken to increase production by drilling to nearby pocket of hydrocarbon to prolong the lifetime of the well, it was decide to go for a multilateral since it was proven as the most economical solution

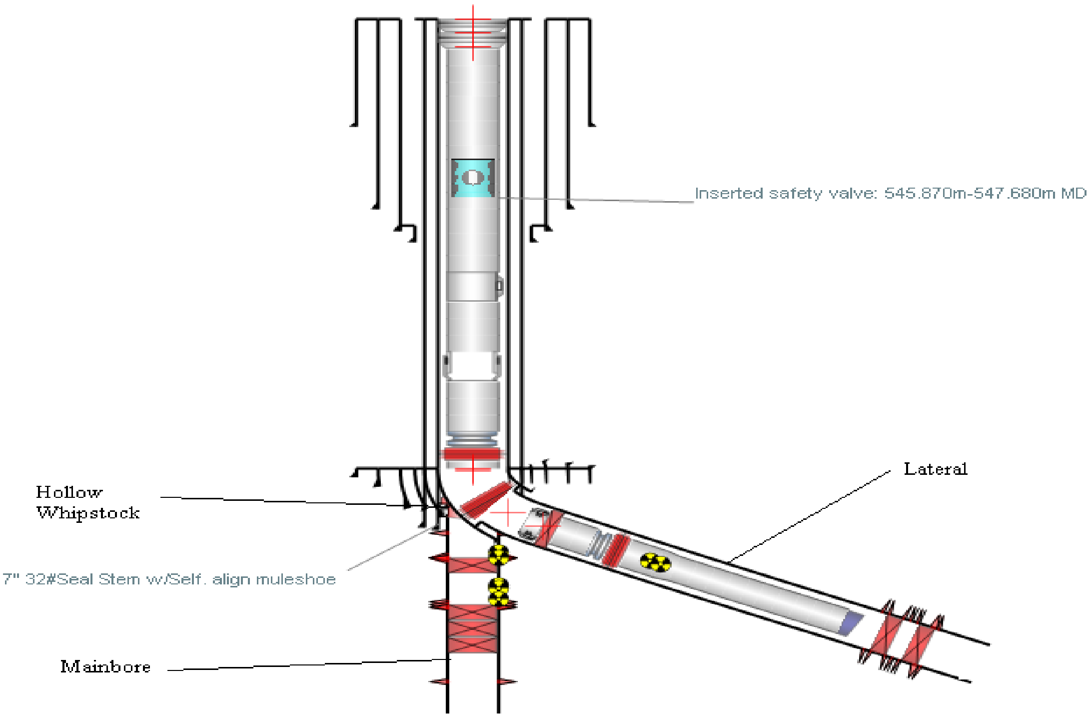


**Figure 19; schematic of Gullfaks 1**

### 4.1.1 Sequence of Operational procedure during running of Starburst Whipstock

- Prior to running the whipstock, the area where the whipstock is to be set is properly cleaned by continued scraping of the area (1740m-1758m) twice, while pumping 1 X bottom ups (BU) with 2000lpm/ 140-230 bar.

- After which recorded up and down weight gave 91/97 tons. RIH to 1980m and 6.5 $m^3$ HEC pill pumped. Same is displaced to surface. When HEC pill reached surface, took pill to slop pit. Pumped 2 X BU with 2000lpm/ 140-250 bar.

- Pumped 15$m^3$ 1,74sg clean brine and displaced same with 8$m^3$ 1,74sg brine. Flow checked well for 10mins.POOH clean up assembly.

### 4.1.2 Mud and Mud Properties:

- The starburst whipstock assembly is run in a standard oil base mud having mud weight of 1,64sg with running speed of 3min/stand to 1750,8m, checked setting depth, bottom part of packer at 1750,8m

### 4.1.3 Type of completion in wellbore;

- The type of Completion here is a cased and perforated completion.

### 4.1.4 Orientation of starburst whipstock:

- Started increasing pump rate in steps to 500lpm/ 3 bar, lost 1,7$m^3$ 1,74sg brine to sump tank, due to opening of pop-off valve on mud pump 1. closed pop-off valve. Continue pumping in steps to 1200lpm/ 48bar, and oriented whipstock to 3 degrees right of right side. Cycled pumps and set whipstock with 3 degrees right of high side. Checked orientation sheared pins with 12ton over pull.

### 4.1.5 Centralisation of Liner:

- RIH with 7” liner and installed liner assembly, while running liner, increased pump rate in steps to 1100 lpm/ 33bar, started losing mud at rate of 15m$^3$ /hr. Mud weight out. 1,65-1,70sg.Continued circulating with 520 lpm/28 bar until 1,66sg MW in return, no losses. Total pumped .55m$^3$. Total Loss; 2,5m$^3$

- RIH with 7” liner on 3 stand 6 ¾” DC, 3 stand HWDP and 5” DP from 1065m to TVD at 2760m. with minor tight spots experienced.

### 4.1.6 Cementing between Liner and Starburst:

- Mu cement head to string, increased pump rate in steps of 100 to 1000 lpm/ 70 bar. Circulated 1 X BU. Maximum gas 45%. Circulated mud until gas readings falls below 1%. MW in/ out; 1,65/1,66-1,67sg. no mud losses.

- Rotated liner with 25-30 rpm/ 6-15kNm. Pumped 3m$^3$ base oil and 15m$^3$, 1.72 sg spacer with 700 lpm/70 bar. Released dart #1. Mixed and pumped 22,3m$^3$ 1,80 sg cement slurry with 700-900 lpm/ 60-40 bar. Displaced cement slurry with 1,5m$^3$ of freshwater to rig floor.

- Released dart #2. displaced cement slurry with 1.65 sg OBM with 1200 lpm/ 85 bar. Rotated string with 24 rpm/7- 20kNm. Stopped rotation of string after pumping 25.8m$^3$ due to high torque reading. Reduced pump rate to 500lpm/22 bar. Bumped plug with 110 bar after pumping 34,9m$^3$ resulting in 97% efficiency. MW in/out ; 1,65 sg -1,66sg . No loss observed. Increased pressure to 180 bar/ 2 min and pressure tested 7” liner to 250 bar/ 10 min. Lined up to trip tank and checked floats.

- Set TSP packer with 40 ton down weight static and 40 ton weight with rotation, observed second shear. Circulated slurry in return approximately 9m$^3$. Flow checked the well. And lay down cementing head.

### 4.1.7 Perforation strategy;

- Attempted to correlate perforation guns at perforation interval but guns slid 110 degrees. POOH. Birds nest occurred in cable at grease junction head when out of hole.

Removed petroline rollers from gun. RIH 3 3/8” guns on tractors without rollers connected to 5/16” electrical cable. Correlated and perforated formation with 4 bar underbalance, POOH and handed over to production and started flowing well to test separator

### 4.1.8 Well Summary

Production started from the lateral when the well was completed and after about 6 months, the whipstock on mainbore was perforated and there was confirmed contribution from the mainbore though exact volume contribution from mainbore and lateral was uncertain. Production continued from mainbore and lateral at about 250sm$^3$/d, 558 M$^3$/d water initially, this low production was suspected due to sand production. Production of oil gradually decrease will a steady increase in water production and the well was completely shut down.

A second lateral was drilled from the existing sidetrack with a starburst whipstock installed. A second whipstock had to be set at 1734 mMD after the first failed to set.
The new lateral came on production with a rate of 600 Sm$^3$/d and 2% water cut in January 2005. The total rate increased gradually with slight constrain from sand production. The Whipstock in mainbore was not perforated as at time of writing this report.

## 4.2 Gullfaks well 2

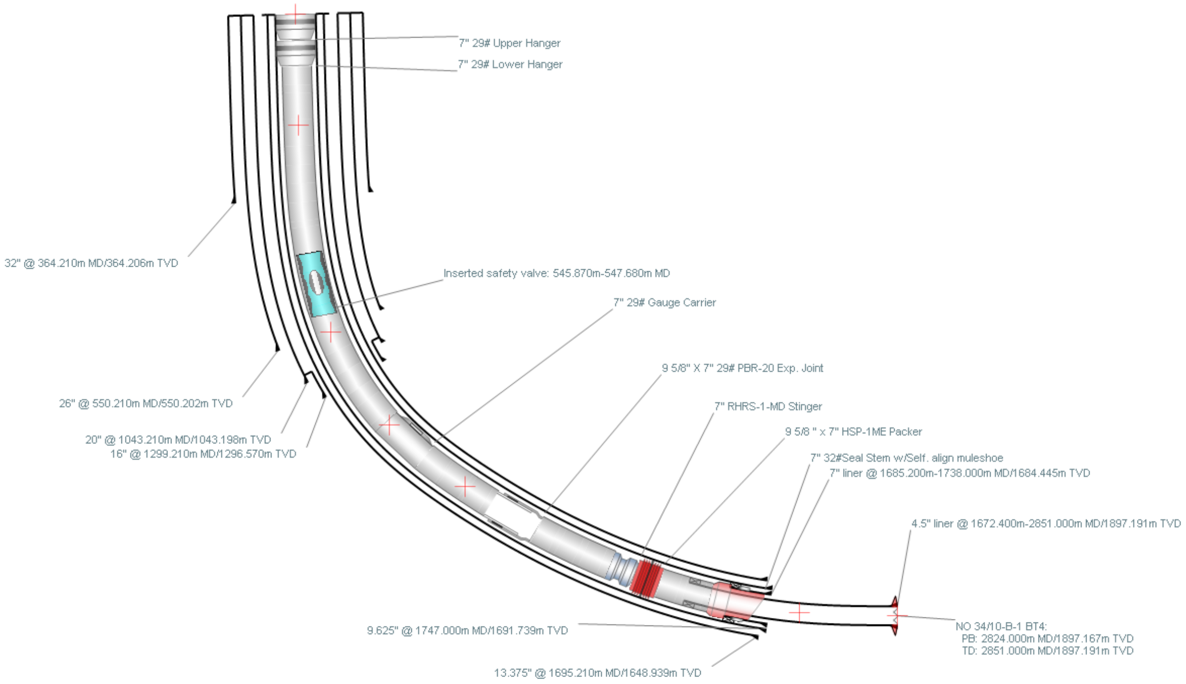


**Figure 20; schematic of Gullfaks well 2**

### 4.2.1 Sequence of Operational procedure during running of Starburst Whipstock,

- Prior to running the whipstock a clean-up/ scraping assembly is RIH on 5" drill pipe, and the interval where the starburst whipstock is to be set 2140-2160m is scraped, while circulating 2 X BU 1,76sg $CaBr_2$ with 2140 lpm/ 240 bar.

- RIH while circulating 500lpm/ 18 bar and tagged timer plug at 2316,1m with 3 ton WOB. Pull up string 0.5m, pumped 4$m^3$ HEC pill flowed by 1.5 X BU at max 2100 lpm /244 bar while circulating 0,5 X BU after HEC pill to surface. There was pressure loss of approximately 20 bar over 5 minutes period.

- During clean-up prior to running of whipstock a 3 3/8" bullnosed wash assembly combined with an 8.5" scraper was run. Bullnose should enter into the 5" expansion joint member (OD/ID 4.6/4.0") stub inside 7" liner (48deg). Several attempts were made with different pumping rates and rotation before gaining access.

- During scraping run, well filled with 1.76 sg brine, while circulating at 2000lpm, pumping pressure of approximately 20 bar over 5 minutes period was observed. The pressure drop was initially interpreted as indication of string wash out (tapered string 2 7/8”, 3 ½” and 5” drill pipe) and circulation was stopped with the stringed pulled out of hole.

### *4.2.2 Mud and Mud properties.*

- 9 5/8 “ starburst whipstock assembly is run with 52 drill pipe in oil base mud with mud weight of 1.55sg

### *4.2.3 Type of Completion in wellbore;*

- The type of completion here is the cased and perforated completion

### *4.2.4 Orientation of Starburst whipstock;*

- RIH to 2213m, worked out torque in string and whipstock was oriented to 1 degree right side of high side and placed bottom assembly at 2210m

- Cycled control valve to closed position, pressured up to 225 bar and set whipstock. Opened control valve, circulated 1250 lpm and verified whipstock toolface at 1 degree right of high side prior to shearing off running tool from whipstock

### *4.2.5 Centralisation of liner;*

- RIH with 7” liner from 2195m to 2744m. Filled drill pipe every 10 stand and spacing out the string.

### *4.2.6 Cementing between liner and Starburst;*

- Broke circulation with 100lpm / 19 bar. Increased rate stepwise to 700 lpm/ 44 bar and circulated 1.5 X BU .maximum gas detected was 17%. Dropped ball and pump with 500lpm. Set hanger and sheared ball seat with 220bar.

- Pumped 3 $m^3$ of base oil and 15 $m^3$ spacer with rig pumps at rate of 500-700lpm/58 - 43 bar. Mixed and pumped 14.5 $m^3$ of 1.8 sg cement with 600 lpm/50-25 bar. Rotated liner with 20 rpm/ 13kNm.

- Displaced cement with 700 – 1000lpm. Rotated liner with 20 rpm/ 14 – 17 kNm and observed 17 bar pressure increase when the second wiper plug was sheared. Bumped plug after 29.4$m^3$ of 1.66sg mud is pumped. Tested liner to 180bar/2 min

- Set packer with 40 ton weight on bit, circulated bottoms up with 2000lpm/ 120 – 128 bar. Performed flow check and lay down cementing head assembly.

### *4.2.7 Perforation strategy;*

- As at the time of writing this report, the whipstock in mainbore was not perforated, its is likely that the perforation of starburst whipstock will be performed when water cut from lateral is at the same level at that of mainbore.

### *4.2.8 Well summary;*

Installed 9 5/8" starburst from exiting mainbore in 2003, milled window as planned (top of window is located at 2202m). Whipstock not perforated yet, will probably perforate and establish communication to mainbore when the water cut is at the same level from the lateral as from the mainbore.

## 4.3 Gullfaks well 3

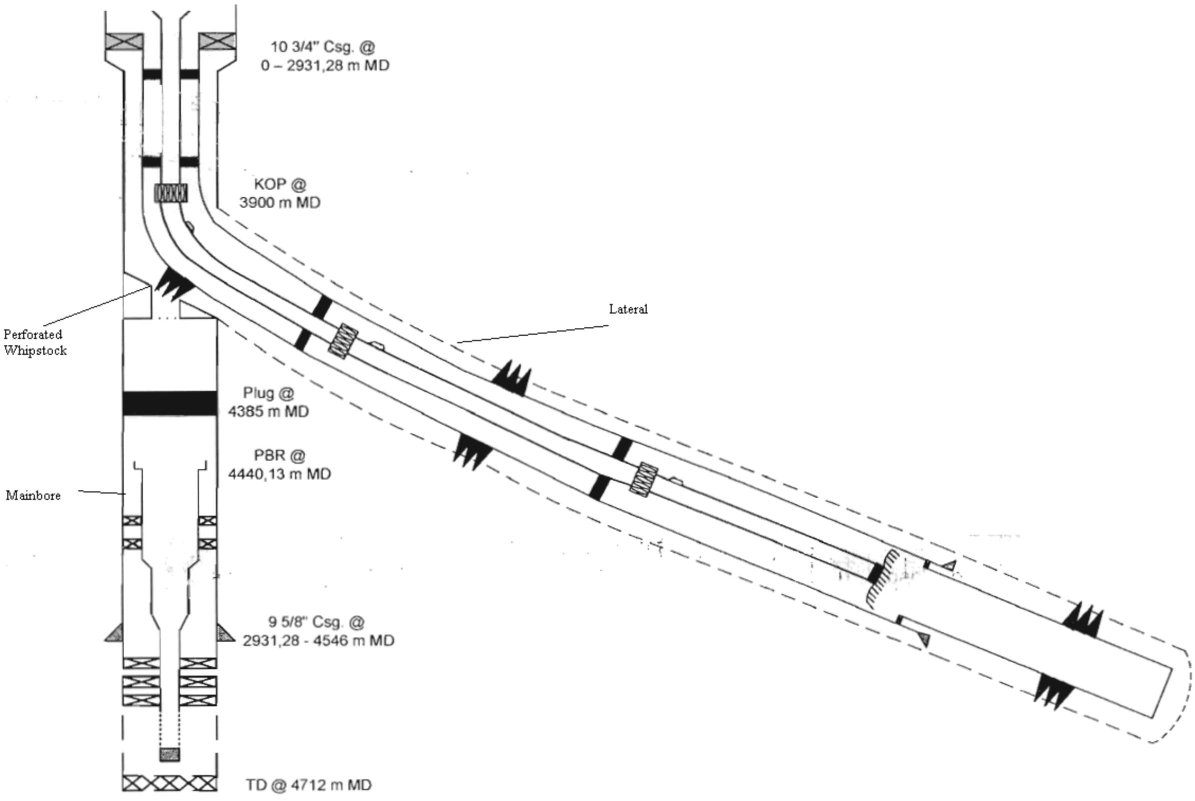


**Figure 21; schematic showing Gullfaks well 3**

### 4.3.1 Sequence of operational procedure during running of starburst whipstock

- RIH with 8 1/2" clean up assembly from 2000 to 4022 m pick up drill pipe from deck. Scraped whipstock setting area 3880-3910 m. Swept hole with high-viscous pill and circulated 2 x BU. POOH to 3100 m.The well was displaced to 1.20 sg brine.

- MU Starburst whipstock and MWD tool. RIH, but string took 10 ton weight at 3060m. Worked string several times, but not able to pass 3066 m. POOH with whipstock assembly to 2354 m

- RIH with cleanup assembly, worked tight area 3046 m and 3070 m. RIH to 3935 m. POOH and worked tight area between 3072 m and 3046 m. POOH and checked liner lap, ok. POOH to 75 m.

### 4.3.2 *Mud and Mud properties;*

- The starburst whipstock assembly is run in oil base mud having density of 1.6sg on 9 joints of 6 1/2” drill collar. Displaced well from 1.20sg brine to 1.63 OBM. Performed injection test of 9/5” liner lap with 1.63sg OBM. Pumped 36.5m$^3$ of 1.92sg high viscous pill and displaced the same with 25.5m$^3$ of 1.63sg OBM

### 4.3.3 *Orientation of Starburst whipstock*

- RIH from 3892m, oriented and set starburst whipstock and packer at 3906.5 with toolface 8 degrees left of high side, Picked up and sheared whipstock release bolt with 23 ton overpull

- POOH from 3898m to 3893m. Closed annular preventer and performed injection test of 9 5/8” liner lap with 1.20sg brine. Pumped with 168 lpm to 510 lpm, pressure on well head then dropped from 131 bar to 240 bar, stopped pumping and the pressure dropped further to 216 bar, before the pressure is bled of.

- Performed new test with 205 lpm, pressure on the wellhead steady up to85bar then started leaking off. Stopped pumping when pressure at wellhead reached 158bar. Bled off pressure and recorded total volume of fluid pumped during injection as 5,2m$^3$ of 1,20 sg.

### 4.3.4 *Centralisation/ running of liner;*

- RIH with 7” liner from 2740m t0 3870m. Circulated and treated mud at 300m and 3870m. Observed unstable well when flow checking at 3870m. Circulated over choke, no indication of instability. Circulated bottom up, flow checked was detected positive.

- Washed down and RIH 7” on 5 ½” drill pipe from 5348m to 5653m. Circulated hole clean with 700 lpm. Made up cement head and spaced out setting depth. Dropped 7” liner hanger setting depth and displaced same.

- Performed 7 attempts to set hanger without success, while attempting to set hanger the running tool released accidentally from 7” liner, liner hanger not set.

- MU and RIH 7” liner running tool to fish 7” liner. Engaged top of 7” liner at 2949m, pulled 7” liner free with up weight of 208ton. Pulled / pumped out of hole with 7” liner, shoe depth had tight spot when pulling out of hole.

- After several attempts with no success, pulled out of hole with 7” liner, lay down totally 99 joints and pup joints on deck. Installed new 9 5/8” x 7” liner hanger, circulated through liner to check for debris.

- RIH with 7” liner on 5” drill pipe. Broke circulation and circulated bottoms ups with loss free pump rate. Polished setting area for liner hanger and washed down to 4412m with 100lpm/35 bar. Increased pump rate in steps to loss free rate of 700 lpm to circulate bottoms up

- Circulated bottoms up at 4400m. Continued washed down with 7” liner to 4900m and circulated bottoms up. Washed down to liner setting depth of 5340m and circulated mud.

### *4.3.5 Cementing between liner and starburst;*

- Circulated and conditioned mud with 500 – 800 lpm/ 44-65 bar. Rotated string with 40 rpm / 26 – 30 kNm. Pumped 15 $m^3$ of 1.64 sg spacer with 795lpm/ 65 bar – 30 rpm/ 25-30 kNm. Pressure tested lines up to 345 bar/5min

- Released first dart, mixed and pumped 42m cement slurry 2.0sg (53$m^3$ of 1.65 sg downhole pumped with 600 – 700 lpm/ 120 – 130 bar and rotated with 30 rpm/ 24-32 kNm.

- Released second dart and displaced cement with 1.60sg mud. Pumped with 800 lpm/ 70-75bar and rotated string with 40 rpm/36 kNm. Bumped plug at 4177 strokes/ 95.7% efficiency on pumps and had full return during cementing job.

- Pressured up liner to 180bar/ 2min and checked plug. Bled off and checked for back flow.

### 4.3.6 Perforation Strategy;

- MU and RIH with Tubing Conveyed perforation guns from surface to depth of 1134m on 3 1/2” drill pipe at running speed of 90 seconds per stand.

- Changed from 3 ½” to 5” inserts in slips and elevator. RIH with perforation guns from 1161m to perforation depth at 3951m on 5” drill pipe at running speed of 90 seconds per stand.

- Broke circulation with 150 lpm – 20 bar pressure at 3953m, and then increased flowrate to 510 lpm – 70/75 bar pressure and established MWD communication.

- Oriented guns 172 degrees to right of high side, Logged Gama Ray and Radioactive markers at 3900.4m and 3903.16m verified position of perforation guns and check if guns orientation is still at 172 degrees to right of high side.

- Perforated whipstock from 3900.6m to 3903m and pressured up string to 128 bar with cement unit. Closed annular preventer and set 20 bar on well head. Pressured up to 230bar / 3min with cement unit. Well head pressure dropped to 10 bar after 2 min, at the same time verified 10 bar pressure peak in cement. Bled down pressure and open annular preventer.

- Flow checked well, well gained 600 l/ 30 minutes

- Closed annular preventer and started circulation with 430 lpm / 92-70 bar. Increased to 750 lpm/ 137 bar. Well head pressure varied from 12 – 21 barr. Had gas over degasser, but no traces of HC gas in brine. Decreased flowrate to 400 lpm/ 47 bars.

- Circulated 1.5 BU with 750 lpm/ 155 bar. Had traces of HC gas in brine at BU. Flow checked well. Pumped slug with cement pumps. POOH with BHA and perforating gun.

### 4.3.7 Well Summary

After completion of this well, there was good indication of breaking glass plug with pressure cycles showing communication through whipstock, although there was a rapid decline in production after a very short time. Report from the production history of the well summarise the initial production from the lateral as 500 sm$^3$/ d of oil and a water cut less than 50 Sm$^3$ of water only for there to be a rapid decline in pressure and the well died after a short time. Opening up the mainbore with maximum drawdown also resulted in no flow from the well. Injection into the lateral bore in an attempt to increase reservoir pressure also proved futile. The last production from this well was in 2006.

## 4.4 Gulfaks 4

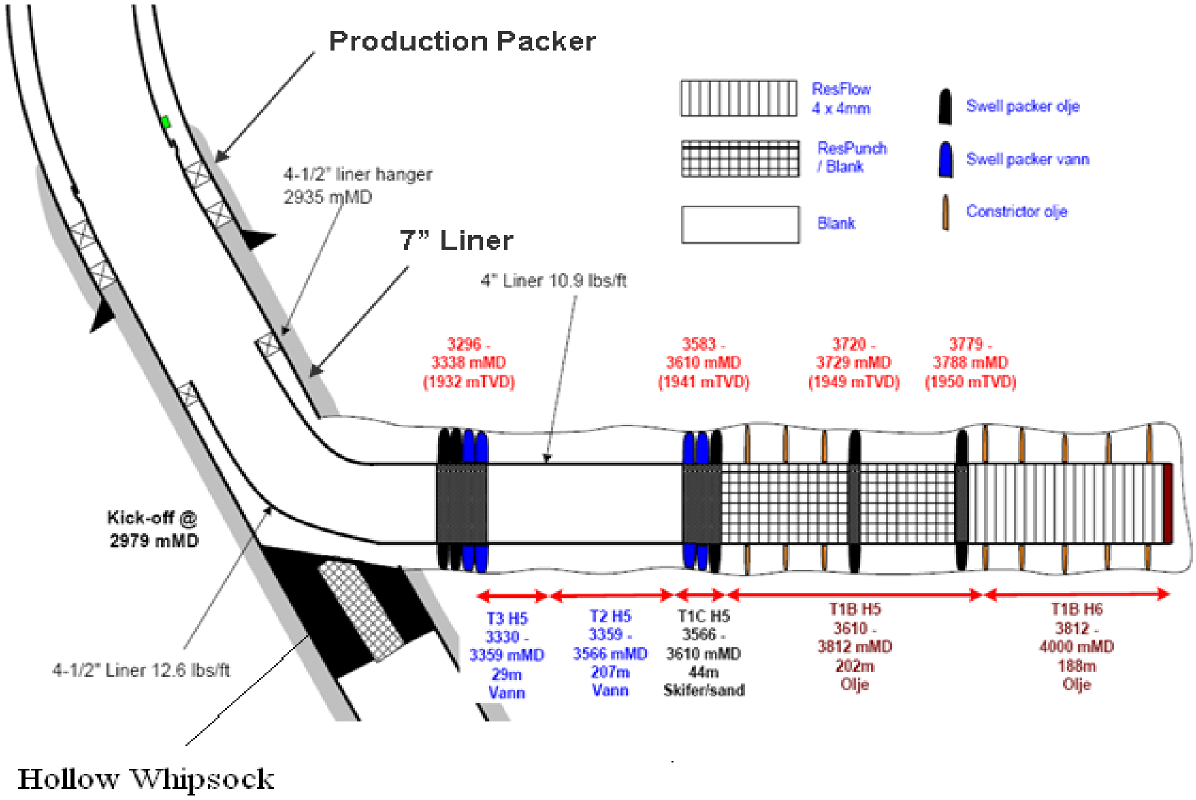


**Figure 22; schematic showing Gullfaks well 4**

### 4.4.1 Sequence of operational procedure during running of starburst whipstock.

- Prior to running the starburst whipstock the 5 7/8” clean up assembly is pick up and RIH with 4 stand 4 ¾” drill collar, 10 stand 4 ¾” jar, 3 1/2” heavy weight drill pipe and down hole safety pipe protection sleeve to 434m.

- RIH with gauge assembly to 985m, filled string and broke circulation with 200 lpm /8 bar. Installed Down hole safety valve protection sleeve at 558m with 9.5ton. Verified setting depth, continued to RIH with gauge assembly from 985m to 2750m. filled string and broke circulation each 500m with 200 lpm

- Continued to RIH with gauge assembly from 2750m to 3010m, broke circulation with 100 lpm/ 7bar and increased pumprate in steps to 500lpm/ 67 bar. Reamed and washed whipstock setting area from 2970m to 2995m with 20 rpm/ 10 – 12 kNm. Pumped down and spotted 15m$^3$ lubricating pill at 3000m while reciprocating and rotating string with 20rpm/ 10- 12 kNm.

- Flow checked well for 15minutes. Meanwhile greased leaking flowline and make up stab in valves for testing. POOH with last stand 3 ½” drill pipe to 435m. Lay down DHSV protection sleeve and Pooh with 3 ½” heavy weight drill pipe.

### *4.4.2 Mud and Mud properties;*

- The starburst whipstock assembly in this well in this case is run in oil base mud having density of 1.65 sg Displaced well from 1.60sg brine to 1.65 OBM warp mud.

### *4.4.3 Types of completion in wellbore;*

- The type of completion here is the cased hole completion for mainbore but the lateral has got open hole completion with perforation of liner.

### *4.4.4 Orientation of starburst whipstock;*

- Positioned bottom of whipstock at 2986m and RIH 10m below setting depth. Pulled up and positioned bottom of whipstock at 2986m.
- Start circulation with 600 lpm/112 bar and orient whipstock to 11 degrees left of high side. Problems to get whipstock oriented accurate at +/- 5 degrees eventually losing 5.5m$^3$ brine in hole while circulating.

- Cycled pumps 3 times to close control valve in BHA. Pressured up string to 200bar to set packer. Verified setting depth of packer, set down 14 ton to pack off elements. Bled off pressure to zero and attempted to pump down string to check if control valve cycled to open position but it was confirmed closed

- Pulled up and sheared off running tool. Start pumps and confirmed control valve is in open position. Closed pipe ram and pressured up well against plug to steps to 260bar

### *4.4.5 Centralisation of liner*

- Pulled up and RIH with 4” screens to 73m. Maximum running speed limited to 3 minutes per joints. Continued RIH with 4” screens / liner string keeping the maximum running speed at 3 minutes per joints. Joint filled up through nozzles in screens and average fluid loss rate of 300 litres per hour.

- Changed from 4” to 4 ½” inserts in elevator and slips. Pulled up and RIH with 4 ½” liner joint from 704m to 1054m. Maximum running speed limited to 3 minutes per joint. Joint filled up through nozzles in screen. At 884m pumped 1,5m$^3$ slug in the liner string due to backflow to drill floor. Pumped after with 1.8m$^3$ of 1.65sg mud, average loss rate recorded was about 300 litres/hr.

- Changed inserts in elevator to 3 ½” drill pipe and RIH with screen / liner string on 3 ½” drill pipe to 2950m.took up and down weight at 1939m. Installed DHSV with 10 ton down weight verified tool set with 3 ton overpull. Monitored loss rate which gave 100-120 litres per hour. set liner hanger,

- Continued RIH to installation depth at 4000m. Set hanger with 126bar , bled of to 50 bar, pulled free with running tool and bled of pressure . Up weight before set hanger was 94 ton and up weight after set hanger is 82 ton. Flow checked well for 15 minutes

# 5 Observation and Findings

Due to the variable and unique conditions of each well, It is quite challenging to compare one well with the next. However it is also worthwhile to note detected observation as one can build on this findings to get a clearer and better understanding on how to tackle the challenges faced in establishing mainbore connectivity in the perforated whipstock

## *5.1 Clogging of Perforations on whipstock;*

For most of the wells where there have been productions from the mainbore before installation of the starburst whipstock, it has been observed that it is mainly a problem to get this mainbore to flow again. Since we can not easily have full access to the mainbore due to the huge cost that will be associated in trying to go through the completion because of the non retrievable nature of the whipstock as well as the cost associated with trying to pull out the completion of the lateral liner. Then one can assume that one of the likely causes of no fluid access up through the mainbore could be due to clogging of the perforation which could be a result of either the fluid properties in the mainbore when running the whipstock and/or the cementing between the face of the lateral liner and the starburst whipstock.

### *5.1.1 Clogging of perforation due to mud*

Clogging of perforations on the starburst whipstock could occur when the wrong mud or mud properties is used. If the wrong mud with undesired properties in used when running the whipstock, various problems can arise that may result in clogging, one of such problem is sagging which simply put is the settling of particle from the drilling fluid.

If the mud in the mainbore is heavy and contains a lot of particles, sagging of these particles might be an issue and this result in plugging the perforations on the whipstock. A good solution to this challenge will be to use a LSOBM with mud weight value less than 1.3 sg. As has been observed on the wells that had communication through the mainbore, example here being the well drilled on the Smøbrukk field.

The illustration below shows how clogging of perforation may occur due to the different displaced mud during the installation of the whipstock, since it been well observed in the different case studies that after setting the whipstock it may not be perforated immediately, then there is high possibility of sagging occuring in the fluid below the whipstock and this can subsequently lead to clogging of perforation whenever  the access to the mainbore is established at a later date.

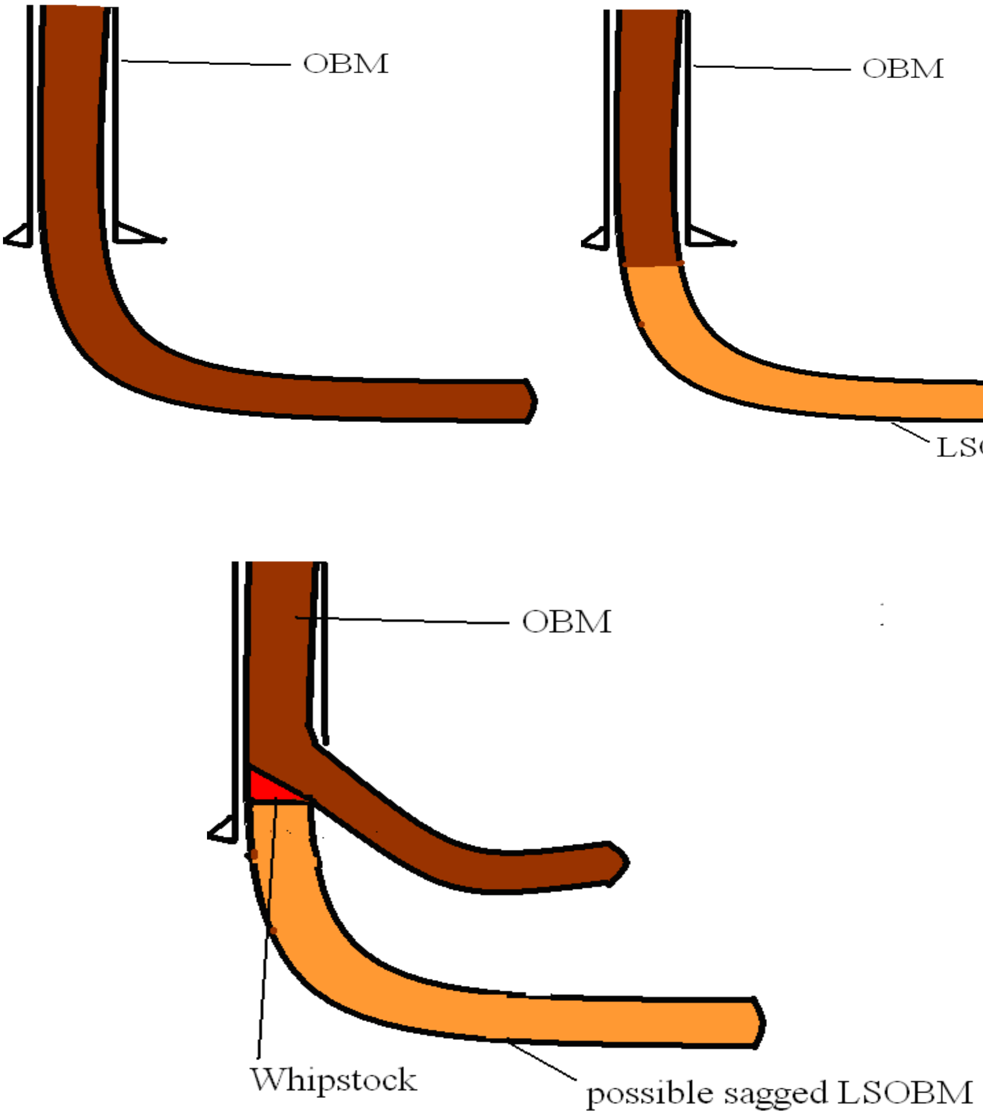


**Figure 23; showing possible change effect of fluid after staying a while in the wellbore**

### 5.1.2 Clogging of perforation due to cement between whipstock and liner

Another potential source of clogging to the perforation of the whipstock is how well the cement bound the surface between the starburst whipstock and the liner; a good cement job will ensure better holes when perforated than when we have a poor cement job between the face of the whipstock and the liner. This is always going to be a challenging, given the fact that it is quite difficult to get an even clearance between the two surfaces and also the effect of the steep surface nature of the whipstock will always want to push down the cement slurry toward the lower part of the whipstock, other suspected challenges could be as a result of the fact that cement generally do not perform well as structural components unless there is sufficient surface area to create adhesion[12]. However in the case of the junction, there will be very little surface area and reliable placement of cement will be difficult in this small surface area environment. The figure below shows an example of a good cement job performed between the liner and the whipstock.

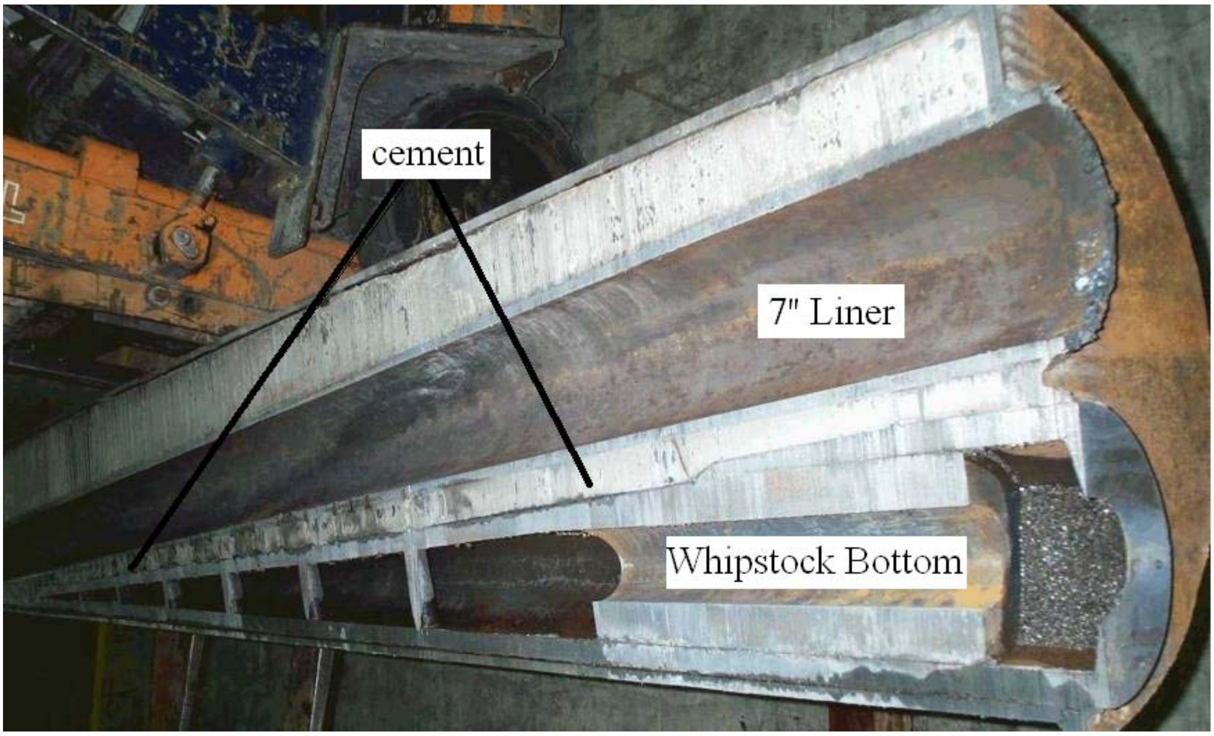


**Figure 24; Showing cement between whipstock and liner**

## 5.2 Perforation Strategy

As it has also been well document earlier we can either run the perforation gun for the whipstock on wireline or it can be conveyed in the tubing. In performing this operation with either method, it all comes down to accuracy in placing the perforation charges at the correct depth and required angle. It has been observed that when running the perforation gun on wireline, the depth to the point of perforation is easy to correlate however orientation of the gun may be more challenging, but it is considered a good method.

whereas when using tubing conveyed method, the drillpipe is more uncertain with respect to depth correlation and might make it even more challenging orientating the gun to the required angle. Although following good procedure when using this method has proven a good and reliable method when performed by experienced personnel

The illustration shows the orientation tolerance during perforation of the whipstock.

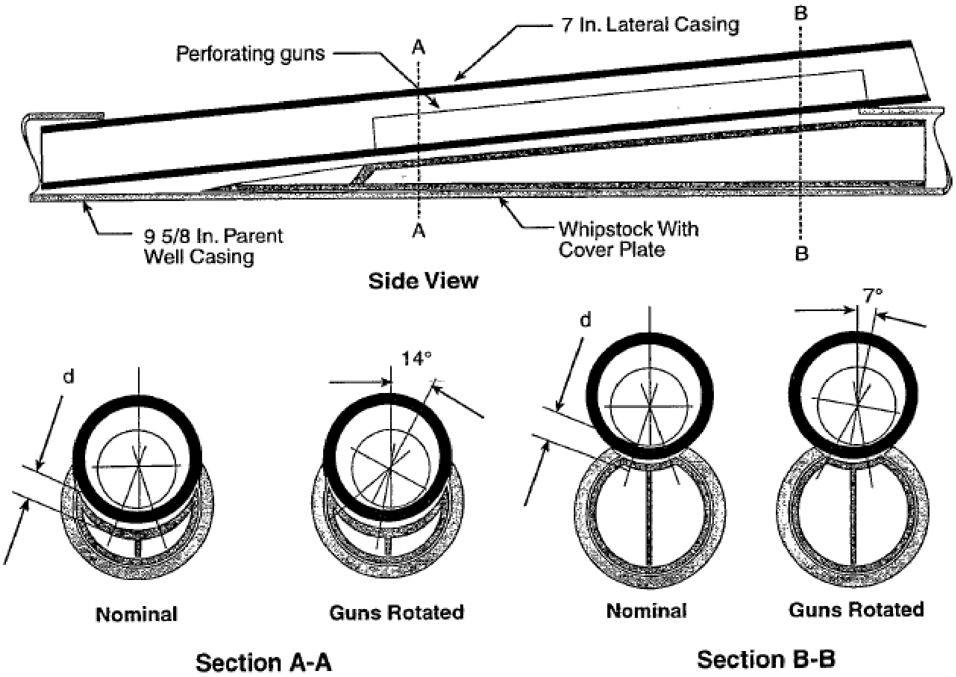


Figure 25; Showing perforating gun orientation tolerance

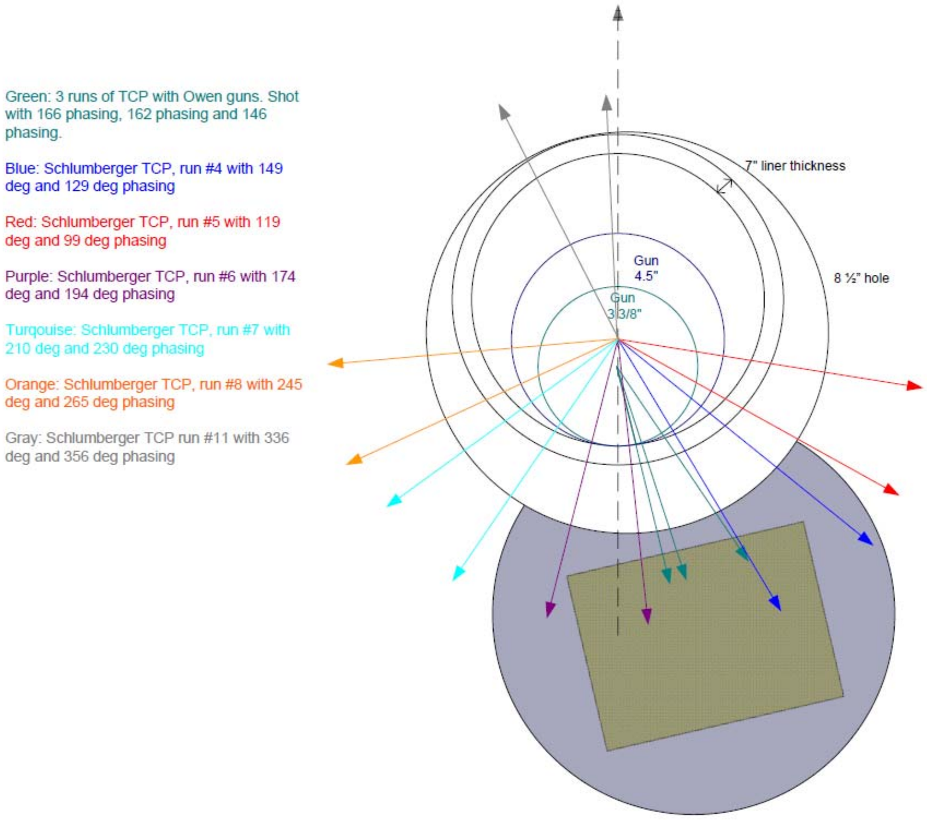


Figure 26; Illustration showing perforation attempts

# 6 CONCLUSION

The main area where a lot of work is needed, is the area of selection of drilling and completion fluid, It is very important in ensuring that we have the right drilling and completion fluid that will satisfy most condition in the wellbore, although this is always challenging to achieve due to high degree of variation in the formation properties, but studies have shown that having a LSOBM with weight above 1,3sg is likely to sag after it has been left in the mainbore for quite sometime and there is a possibility of this leading to clogging of holes after perforation of the mainbore.

A greater degree of accuracy is still required in both depth correlations and orientation of the perforation guns to ensure that the right interval on the face of the whipstock is perforated. Also Underbalance perforation from the mainbore may be the key to improving the performance of the well although there have been cases where there was still no connectivity after this exercise

Debris control and management are of utmost importance during the construction of a multilateral well, hence specific operations during the commissioning and construction phases that are likely to generate more debris should be carefully planned and address accordingly to minimise generation of debris that could plug perforation.

A good cement job between the liner and the starburst is also essential as this will help to make better holes after perforation of the whipstock in the main bore. Since will know that cement is very good in compression but fails easy when the is an impact force, then the design should be as such that when the cement in placed in between the liner, care must be take so there is minimal force that will induce impact on the cement. Also the possibility of altering the cement properties to increase the resistance to failure due to sudden impact should be considered as well.

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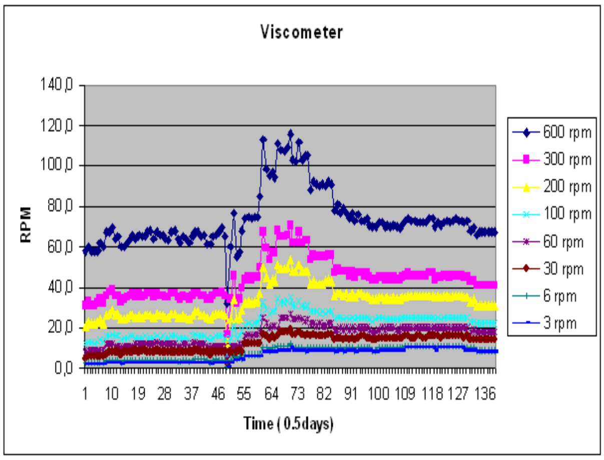
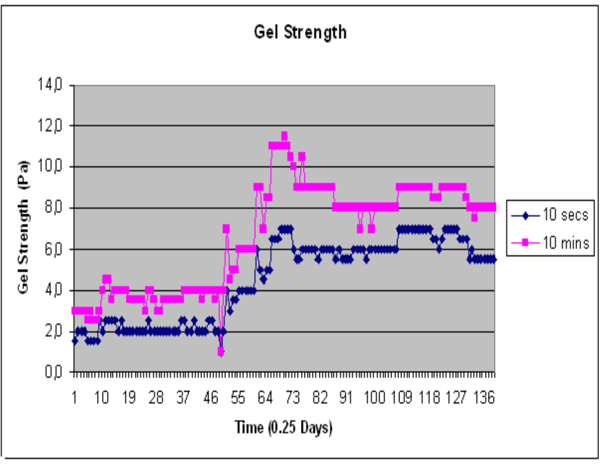
# Appendix

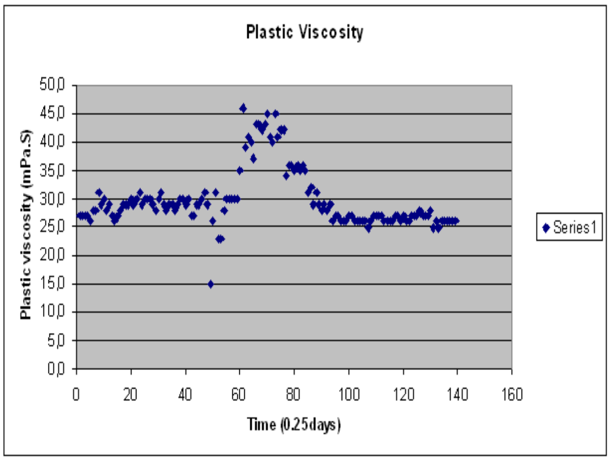
## *Appendix A: Statoil Starburst Summary*

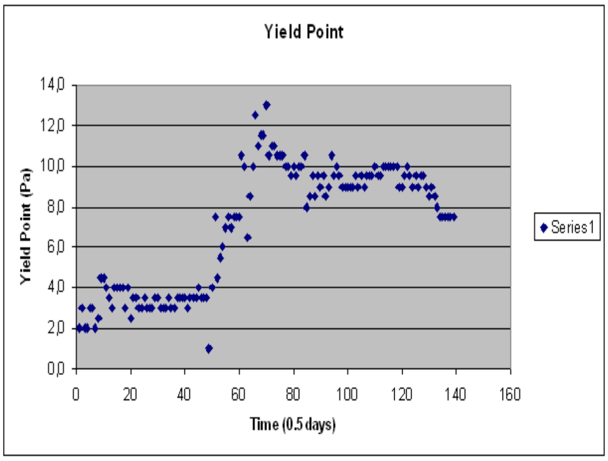
| Wells | Perforation on whipstock | Status | Mud properties in mainbore | Perforation strategy |
|---|---|---|---|---|
| Gullfaks 1 | Perforated 9 5/8" starburst | OK, well shut due to sand/water | 1,65sg OBM | Owen gun /wireline |
| Gullfaks 2 | Not perforated | OK | 1,66sg OBM | Not applicable |
| Gullfaks 3 | Perforated 9 5/8" starburst | No contribution from mainnbore | 1,64sg OBM | Owen gun /Drillpipe |
| Gullfaks 4 | Not perforated | Ok | 1,57sg OBM | Not applicable |
| Gullfaks 5 | Perforated 9 5/8" starburst | Most Likely | 1,75sg OBM | Owen gun /Drillpipe |
| Gullfaks 6 | Perforated 9 5/8" starburst | Ok | 1,67sg OBM | TCP |
| Gullfaks 7 | Perforated 9 5/8" starburst | No contribution from mainbore | 1,65sg OBM | TCP |
| Gullfaks 8 | Perforated 9 5/8" starburst | No contribution from mainbore | 1,60sg OBM | Owen gun /Drillpipe |
| Vestflanken | Perforated 9 5/8" starburst | Operation successful | 1,55sg OBM | Oriented TCP |
| Smørbukk 1 | Perforated 9 5/8" starburst | Ok, Used as gas Injector | 1,20sg OBM | Owen gun /wireline |
| Smørbukk 2 | Perforated 9 5/8" starburst | No contribution from mainbore | 1,24sg OBM | TCP |

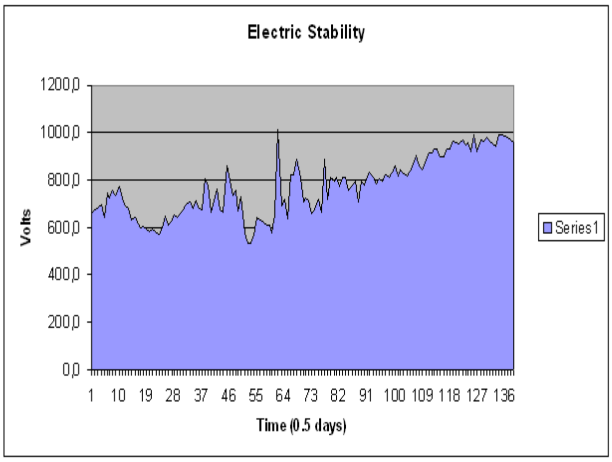
## *Appendix B; Summary of Fluid properties for Gullfaks well 1*

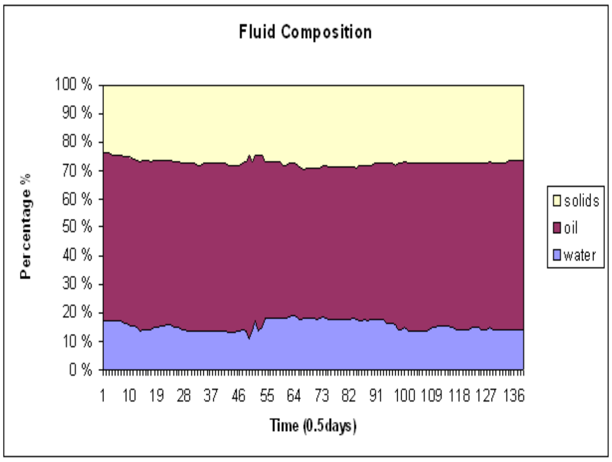




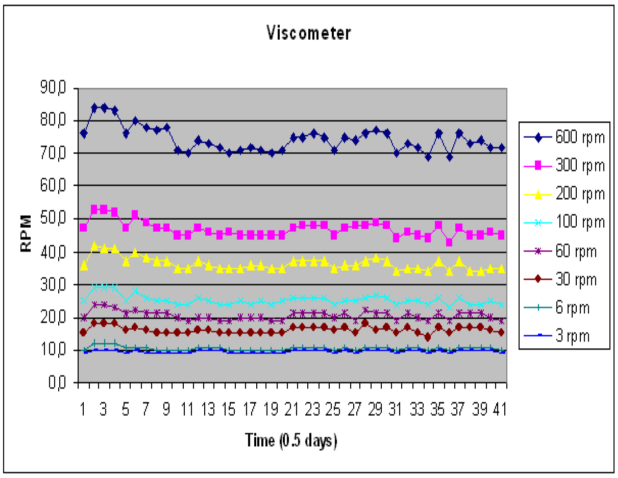


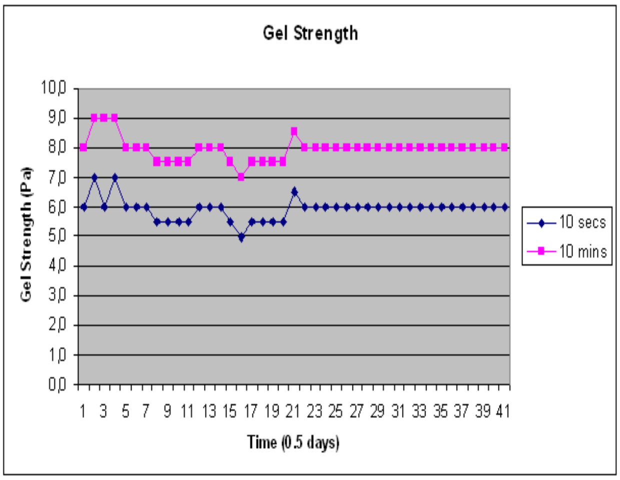


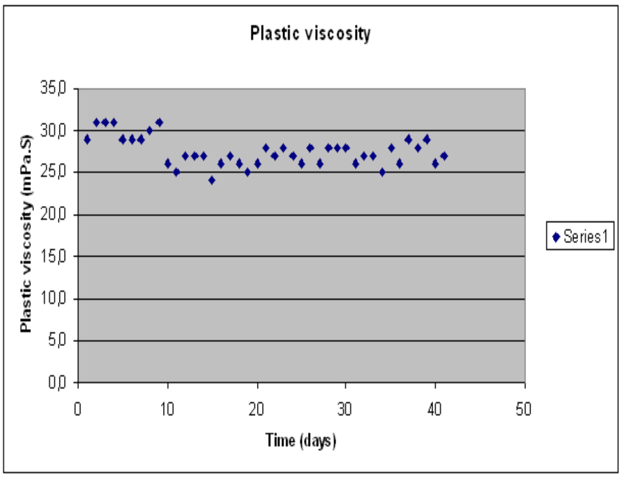


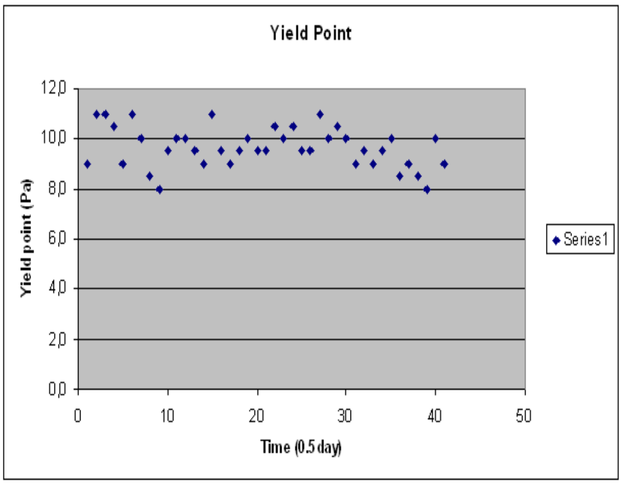


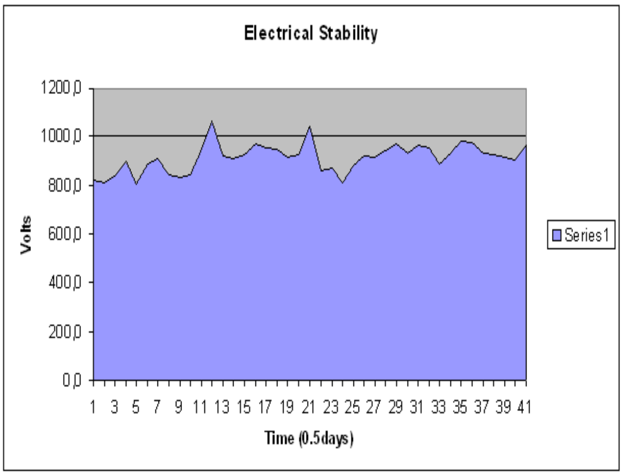
## *Appendix C: Summary of Fluid Properties for Gullfaks Well 2*

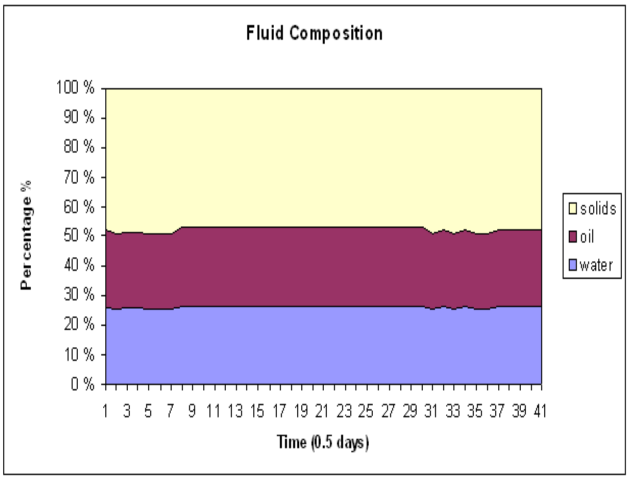




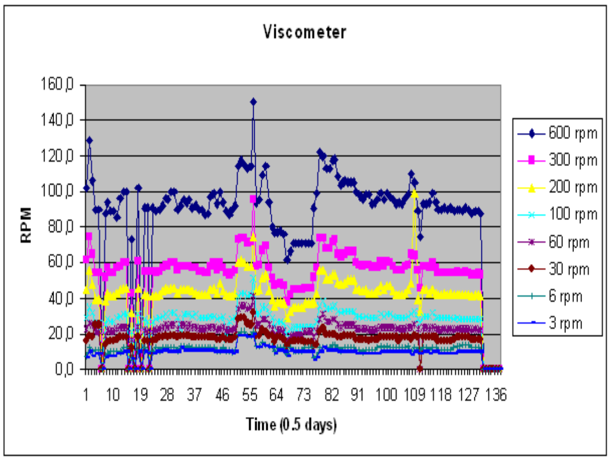


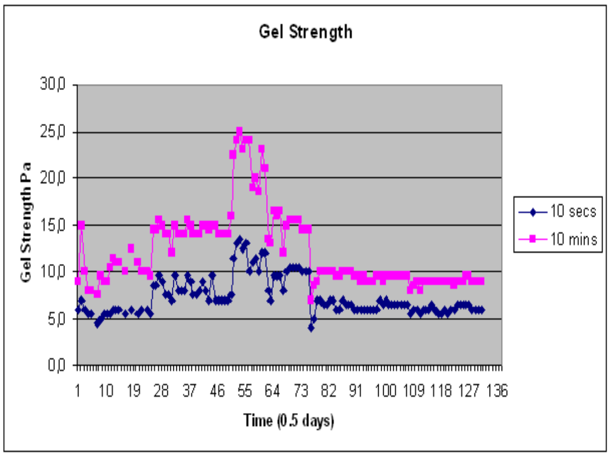


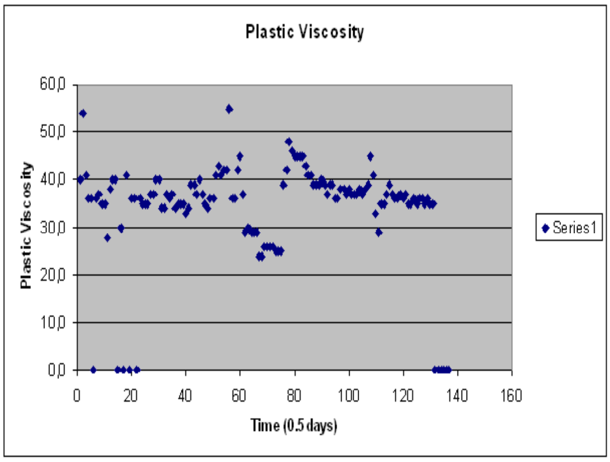


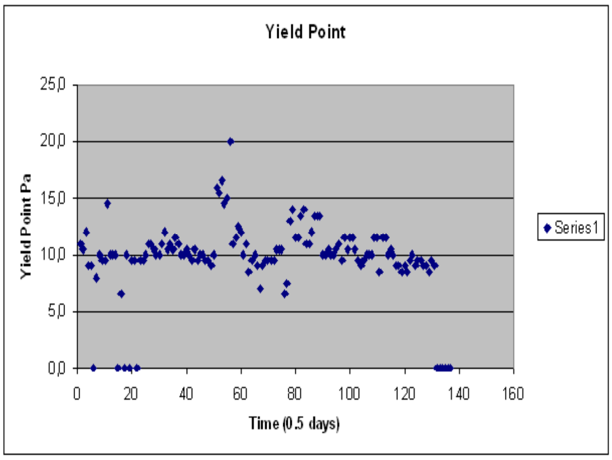


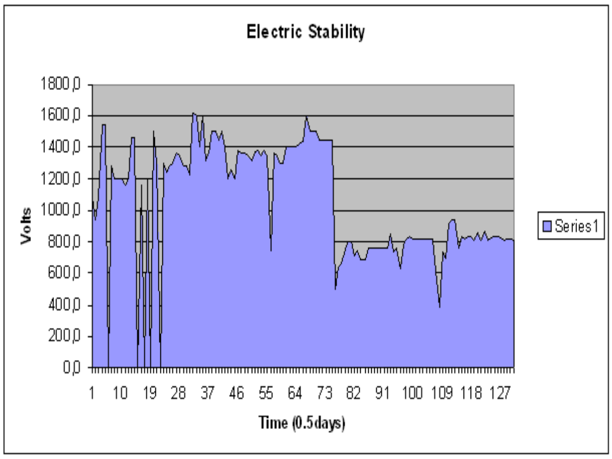
## *Appendix D. Summary of Fluid Properties for Gullfaks well 3*

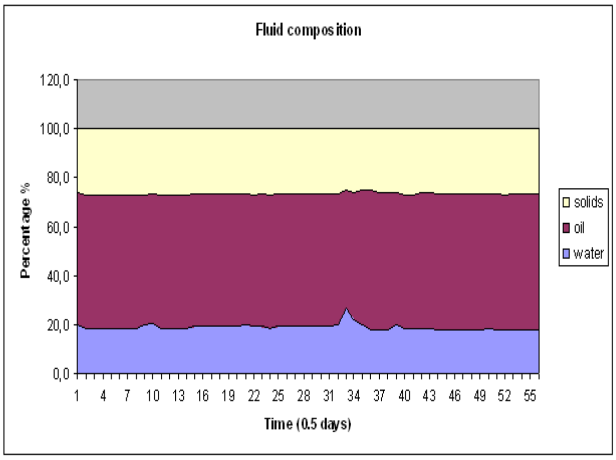












# *Appendix E: Summary of Fluid Properties for Gullfaks Well 4*