University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: Offshore Technology / Marine and Subsea Technology	Spring semester, 2013 Open
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Thesis title: Scale Operations from Monohull Vessel	
Credits (ECTS): 30	
Key words: Scale, Black Eagle hose, Edda Fauna, Seven Viking, Statoil IMR	Pages: 50 Bergen, 30.06.2013

Abstract

The advances within the oil and gas industry have provided opportunities to expand into deeper and more remote areas. One of the most important technological advances comes from the development of subsea equipment. The increase in subsea developments also resulted in advances of other technology. Inspection, maintenance and repair (IMR) operations is an important element in keeping subsea developments cost-effective. Scale is an unwanted chemical reaction that can occur during hydrocarbon production. It is one of the most common problem areas in the oil and gas industry especially for subsea developments. Scale management from monohull vessels is essential for many subsea developments.

Scale operations are performed from monohull vessels with advanced scale treatment equipment. An important piece of the equipment is the Black Eagle hose system. During scale operations the Black Eagle hose is connected subsea and used to pump chemicals into the required well. The setup of the Black Eagle hose system can lead to high forces on the hose during launch and recovery. This setup and the structural strength of the hose set the limiting factor for scale operations to 4 m Hs.

This thesis investigates the scale treatment system on Statoil IMR vessels. Focus has been on locating challenges regarding the Black Eagle hose system used on Edda Fauna. After assessments of the found challenges were performed, work was initiated to suggest improved solutions to the Black Eagle hose system. Calculations have been made to check the feasibility and the potential of the proposed improvements.

The concluding part of this thesis is based the results from the calculations and on experiences from, studying scale, traveling offshore and discussions with offshore and Statoil personnel.

The proposed improvement solutions to the Black Eagle hose system can lead to several of the problem areas being improved. The conclusive remarks indicate that the proposed ideas are feasible and will lead to increased productivity for future operations.

The results and conclusions made in this thesis should be used as a basis for further discussions regarding improvements to the Black Eagle hose system and the IMR vessels.

Preface

I was offered a position in Statoil and will start working in the IMR department from 01.08.2013. The possibility to cooperate with Statoil for a thesis would be a good introduction to the company and also it would create possibilities to acquire specific knowledge towards future work. Together with internal supervisor Eiliv Janssen a dialog with Statoil towards cooperation for a master thesis was started in January. Statoil found that this could be beneficial for both parties, and work toward a topic of interest was initiated.

The work for this thesis started in March with an objective to study scale in connection with the newly acquired IMR vessel, Seven Viking. As the work progressed during the spring, the scope was narrowed into an improvement study for the scale treatment systems on both Statoil IMR scale vessels. The focus was set on the Black Eagle hose system and how to improve this for future operations.

The work performed in this thesis is due to the outcome of a literature study, an offshore trip, hand calculations and interviews with Statoil personnel and crew members on Edda Fauna. Much of the work with this thesis has been to gain knowledge about scale, scale operations and scale management. Many hours has been used on phone calls, writing Emails and in meetings finding and discussing relevant information for this thesis. One of the most educational experiences was the two week offshore trip on Edda Fauna in May observing scale operations. The opportunities of observing and learning the execution of actual operations lead to a very good insight into scale management.

The work has been carried out at the Statoil offices in Bergen and offshore on Edda Fauna.

I would like to thank my supervisor Eiliv Janssen for the assistance in providing me the opportunity to write my thesis in cooperation with Statoil, and for all his feedback and guidance during the semester. I would also like to thank future coworkers Hans Kristian Kvangardsnes, Sveinung Finseth and all the other employees at the Statoil IMR department for all the guidance and support.

Fredrik Taule

Bergen, 30.06.2013

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Abbreviations:

Abbreviation	Definition
CCR	Central Control Room
DP	Dynamic Positioning
IMR	Inspection, Maintenance and Repair
P&ID	Process and Instrument Diagram
ROV	Remotely Operated Vehicle
SCTR	Scale Treatment
LFL	Low Flashpoint Liquid < 60°C
LFL*	Low Flashpoint Liquid < 43°C
STCR	Scale Treatment Control Room
ETC	External Tree Cap
ETCRT	External Tree Cap Running Tool
MHS	Module Handling System
WROV	Working Remotely Operated Vehicle
OBSROV	Observation Remotely Operated Vehicle
IBC	International Bulk Chemical
RFO	Ready For Operation
ID	Inner Diameter
OD	Outer Diameter
BSV	Down Hole Safety valve
Hs	Significant Wave Height
DMA	Dead Man Anchor
N/A	Not Applicable
WoW	Waiting on Weather

1. Introduction

1.1 Offshore scaling problems

Scale is an unwanted chemical reaction that can occur during hydrocarbon production. It can cause damages towards equipment, production losses and lead to large costs from having to perform scale treatment operations. Scale management and treatment is necessary for many oil and gas fields and consequently there is a large market for this type of work in the oil and gas industry.

The fear of possible scaling problems in oil and gas fields did in the past lead to the selection of field development solutions to lean towards fixed platforms and fixed wells instead of utilizing subsea field developments.

The development of scale management was a huge boost for the expansion of subsea developments. And the continued progression has increased both the subsea development possibility and profitability. With subsea field developments it has become profitable to develop more and also smaller fields than before. Illustration of the subsea field development on Ormen Lange is displayed in Figure 1.

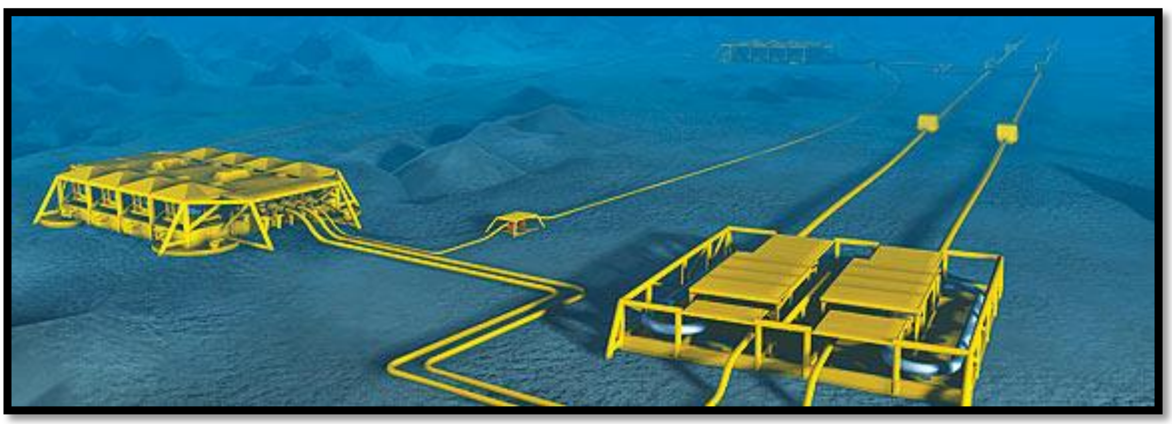

Figure 1 Ormen Lange field development (FMC Technologies, 2013)

Previous practice was to abandon or use expensive drilling rigs to perform complete workover on scale infected subsea wells. Now specialized monohull vessels with advanced internal scale treatment systems perform effective chemical; scale removal and inhibitor treatments. The improvement in scale management has led to huge savings in both time and costs for scale operations, and work is still being performed to increase the profitability.

Preemptive scale management is still most common in connection with subsea wells, as for fixed wells it can be more profitable to have the platform do workover on the wells if scale should ever occur.

Scale operations in Statoil are planned by the IMR department on assignment from the departments operating the fields in need of scale treatments. The IMR department controls two vessels capable of performing scale operations. Edda Fauna has performed several scale jobs, and Seven Viking a newly built ship expected to perform its first scale job in autumn 2013.

1.2 Project scope

The scope of this thesis is to look into scale operations performed by monohull vessels. An investigation of challenges related to the scale system, procedures and equipment on the two scale vessels on contract with Statoil will be performed. The thesis will narrow the focus towards the Black Eagle hose system used during scale operations on Edda Fauna. Alternative solutions to the challenges are to be proposed, calculations performed and feasibility checked. The results and conclusions made in this thesis should be used as a basis for further discussions regarding improvements to the IMR vessels.

1.3 Limitations to this thesis

- When it is referred to scale it is meant inorganic scale, as organic scales and its related issues are usually dealt with under different names.
- Mechanical scale removal is of little interest to this thesis and is therefore only briefly described.
- When collecting historical data from previous scale operations there were some minor discrepancies and some assumptions had to be made.
- Prices specified in this report are only to be indicative towards equipment costs.
- The hand calculations of pressure loss in chapter 5.1 are based on data from a well on the Norne field in the Norwegian Sea. The data from this well will serve as representation as it is a close match for the majority of wells in the current scale management program of Statoil. That being said all wells are different and small variances will occur in most wells, and there will be some unusual wells with larger differences. Simplifications have been made in respect to the numbers being put into the calculations, i.e. only an averaged fluid is accounted for.
- All calculations are performed with a Black Eagle hose length of 750 m, a shorter hose can also be relevant to use. The calculations for shorter hoses will give conservative answers compared to the ones achieved with 750 m hose.
- Even though there are two IMR vessels, both capable of performing scale operations, only Seven Viking is describe in detail, this also goes for the onboard systems. The two vessels are similarly equipped so the description of the systems onboard will be practically identical on Edda Fauna.
- An approximated day rate of 1 million NOK is used.

1.4 Methodology

1.4.1 Scale state of the art study

The initial part of this Master thesis is a study into scale. This is to provide an elementary understanding around the subject of scale. The important subjects are as follows; what scale is, why scale occurs, scale management, and history and progress of scale management. Theory is to be researched and presented.

1.4.2 Calculations

Hand calculations will be performed in this thesis to ensure that suggested solutions are feasible and favorable compared to todays practice. Table 1 describes calculations performed and the reasons to why they were executed.

Table 1 Overview of the calculations to be performed and associated reasons, for calculations made in this thesis.

What is calculated	Reason for calculation
Pressure loss through 2" Black Eagle hose, with a flow rate of 1200 l/min	To check if theoretical calculations reflects the known pressures.
Pressure loss through 3" Black Eagle hose, with a flow rate of 1800 l/min	To check if it is feasible to use a 3" Black Eagle hose and to find the necessary vessel pump pressure
Yearly pump hours from 2010 to 2012	To find the yearly pump times and how much time could been saved by using a 3" Black Eagle hose with a pump rate of 1800 l/min
Winch system prices	Prices not available.
Black Eagle hose prices	Prices for procuring both 2" and 3" Black Eagle hoses. Prices for rental of current system.
Buoyancy collar time consumption and prices	To find the potential time savings of new system. Prices not available.

1.4.3 Proposed improvement solutions

After investigations into the Black Eagle hose systems problem areas are performed, alternative solutions are to be proposed and lined out.

1.5 Thesis outline

Chapter 2 is a wide introduction to the subject of scale, equipment and Statoil's procedures.

Chapter 2.1 - 2.5 is an introduction to what scale is and the reasons that it forms, it also describes scale management and the different methods to remove and prevent scale, and provides information regarding the progression of scale management in the later years.

In chapter 2.6 Seven Viking an IMR vessel constructed for scale operations is described along with the most important scale equipment.

Chapter 2.7 contains a description of execution and procedures of a scale operation on the IMR vessel Edda Fauna.

In chapter 3 equipment and procedures considered to be non-optimal are described.

Chapter 4 is a description of the proposed improvement ideas.

Chapter 5 is calculations and a presentation of the results.

Chapter 6 contains discussions regarding proposed ideas and calculations.

Chapter 7 summarizes and concludes the ideas and discussion.

Chapter 8 is a short description to help guide towards future work.

2. State of the art

2.1 Scale

Scale deposits are one of the most common problem areas in the oil field. Scale can lead to many troubles including equipment damages, reduced production, and blockage of the well. Scale can occur in both production and injection wells where water is present. (Schlumberger, 2013)

The reason scale forms are disruption of the fluid equilibrium in a formation or reservoir. Scales are solid deposits that form as a result of precipitation of mineral compounds present in water. Shown in Figure 2 is a picture of scale deposits in a pipe. The solid precipitate can settle on the surface of a material or it can float around in the water. Floating scale solids can cause problems such as formation plugging and settling scale can cause restriction of flow and damage equipment. Corrosion of metals can often be accelerated under scale layers. (Bai & Bai, 2010)

Scale can occur already during the drilling process of a well. If the drilling mud is incompatible with the water in the formation scale can start to precipitate. In many wells scale is initially not a problem, but during the lifetime of the well conditions may change and scale begin to form. Water injection wells can cause scaling if the injected water is incompatible to the water in the formation. (Bai & Bai, 2010)

“Before a well is drilled and completed, the fluids in the formation are in equilibrium with the surroundings. However, when the well is drilled and starts to flow, the equilibrium is disturbed, and solids may start to precipitate. Inorganic deposits are called “scales” and organic deposits are referred to as “waxes” or “asphaltenes”. Additional organic solids include naphthenates, diamondoids, and gas hydrates. Any of these materials can precipitate in the formation, in the near-wellbore region, in perforations, in tubulars, on downhole completion equipment, and in surface equipment.” (Frenier & Ziauddin, 2008)

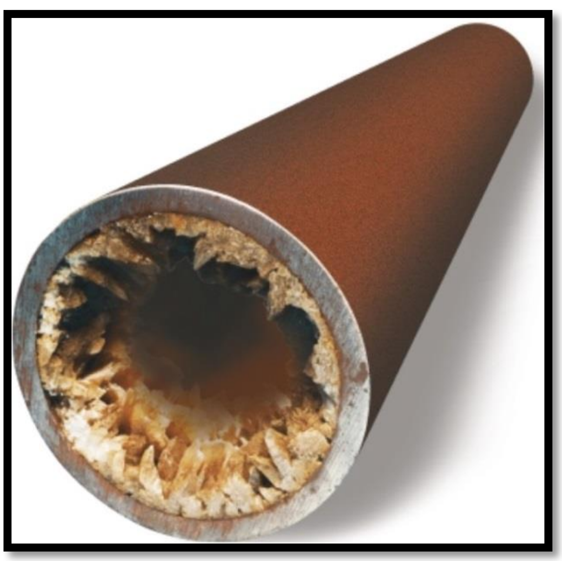

Figure 2 Pipe containing gypsum scale (Crabtree, Eslinger, Fletcher, Miller, Johnson, & King, 1999)

The disturbances in the equilibrium include pressure and temperature changes, precipitation caused by chemical reactions, dissolved gasses or incompatibility in mixing of different waters. (Schlumberger, 2013)

Scale is often divided into two categories, inorganic and organic scale. In most cases when scale is being discussed it is referred to inorganic scale, as organic scale is often referred to under other names.

2.1.1 Inorganic Scale

"Inorganic scales are minerals that form on a surface because of the saturation of the local environment with an inorganic salt." (Frenier & Ziauddin, 2008)

Common inorganic scale deposits in oil wells and the most important factors affecting solubility are shown in Table 2. In Table 3 the most common causes and removal chemicals for these scale deposits are shown.

Table 2 Common scale deposits (Bai & Bai, 2010)

				Most important factors affecting solubility						
Deposit	**Chemical formula**	**Mineral name**	**Partial pressure CO**	**pH**	**Total pressure**	**Temp.**	**Total salinity**	**Corrosion**	**H_2S**	**O_2**
Calcium carbonate	$CaCO_3$	Calcite	X	X		X				
Calcium sulfate	$CaSO_4 \cdot 2H_2O$ $CaSO_4$	Gypsum Anhydrive			X	X				
Barium sulfate	$BaSO_4$	Barite			X	X				
Iron carbonate	$FeCO_3$	Celestite	X	X		X	X	X		
Iron sulfide	FeS	Trolite		X			X	X	X	
Iron oxide	Fe_2O_3 Fe_3O_4	Hematite Magnetite		X X			X X	X X		X X
Sodium chloride	NaCl	Halite		X		X				
Magnesium hydroxide	$Mg(OH)_2$	Brucite		X						
Silicates	Variable			X		X				

Table 3 Causes and removal chemicals for common scale deposits (Bai & Bai, 2010)

Deposit	Occurrence	Chemical Formula	Mineral name	Most frequent causes of scale deposit	Removal chemical
Calcium carbonate	Common	$CaCO_3$	Calcite	Mixing brines, changes in temperature and pressure	15% HCl
Calcium sulfate	Common	$CaSO_4 \cdot 2H_2O$ $CaSO_4$	Gypsum Anhydrive	Mixing brines, changes in temperature and pressure	Converting solutions EDTA type dissolvers
Barium sulfate **Strontium sulfate**	Common Not Common	$BaSO_4$ $SrSO_4$	Barite Celestite	Mixing of brines Mixing brines, changes in temperature and pressure	
Iron carbonate	Common	$FeCO_3$	Sidertite	Mixing brines, changes in temperature and pressure	Sequestered acid
Iron sulfide	Common	FeS	Trolite	Corrosion by sour crude or H_2S gas	Sequestered acid
Iron oxide	Common	Fe_2O_3 Fe_3O_4	Hematite Magnetite	Reaction of oxygen with dissolved ferrous ion	Sequestered acid
Sodium chloride	Not Common	NaCl	Halite	Evaporation of water and addition of MeOH for hydrate control	Water or 1-3% HCl
Magnesium hydroxide	Not Common	$Mg(OH)_2$	Brucite	Excessive amounts of oxygen enter the well, high temperature	15% HCl
Silicates		Variable		Cooling of hot brine high in dissolved silica	HCl:HF acid mixtures

2.1.2 Organic Scale

Organic scales are caused by precipitation of organic deposits and can contain waxes, asphaltenes (shown in Figure 3), gas hydrates, and mixtures of these chemicals, and also naphtenic salts. Organic scales originate from crude oil or gasses and can cause reduced flow or even blockages from the reservoir all the way to the topsides. (Frenier & Ziauddin, 2008)

Figure 3 Picture of asphaltene deposits in a pipe (Janus Energy Resources)

2.2 Impact of scale

Scale can potentially cause huge monetary sums in damages, lost production and scale treatment operations for the oil and gas industry.

Problems caused by scale (Mackay, 2007):

- Formation damage (near wellbore)
- Blockages in perforations or gravel pack
- Restriction or blocking of flow lines
- Safety valve and choke failure
- Pump wear
- Corrosion underneath deposits
- Some scales are radioactive

At the location of where scale forms the flow may be reduced by varying degree and eventually the precipitation can lead to a total blockage of the flow. This can lead to expensive interventions and may in some cases lead to abandonment of the well. It is possible to predict conditions that can lead to the formation of scale, but it is more difficult to determine the location where the scale will form. (Frenier & Ziauddin, 2008)

2.3 Diagnosing scale

When identifying scale in a well the physical process is usually one or more of the following (Paswan, 2008):

- Scale monitoring by Coupons (Surface Facilities)
- Scale monitoring by Gauge Cutter (Down Hole)
- Production performance
- Scale analysis of produced water sample

From produced water there are nine indicators towards scale precipitation in a well (Statoil, 2011):

1. Increasing seawater + decreasing Ba + decreasing PI
2. Decreasing Ba + increasing seawater (check dilution)
3. Decreasing Ba + decreasing/constant seawater + decreasing PI
4. Scale inhibitor below MIC (Minimum Inhibitor Concentration)
5. Decreasing PI + high (95 – 75 %) and decreasing seawater + zero Ba
6. Problems with downhole safety valve (BSV)
7. Change (+/-) Ca + high drawdown + before and after seawater (<10%)
8. Low Ba + Decreasing Ba
9. Preventive/proactive treatment

2.4 Scale management

Scale being such a big problem for the oil and gas industry has led to research and developments into scale and scale treatment. Many good methods for handling of scale have been developed, but there are still use for improvements and new methods. With regard to scale management there is a distinction between prevention and treatment. It is often most cost effective to prevent than to repair, a good scale management plan is therefore important to establish.

"When scale forms, a fast, effective removal technique is needed. Scale-removal methods involve both chemical and mechanical approaches, each with its own niche – depending on the location of the scale and its physical properties." (Crabtree, Eslinger, Fletcher, Miller, Johnson, & King, 1999)

Scale management and removal is today executed by common types of well intervention operations. The most common scale management and removal techniques include:

- Mechanical scale removal
- Scale dissolver (also known as chemical removal)
- Scale inhibitor treatment

Several tools are developed to help in the optimization of scale management.

2.4.1 Mechanical scale removal

Mechanical removal can normally be divided into these categories:

- Abrasive
- Abrasive/hydraulic
- Hydraulic
- Thermal

Normal mechanical scale removal systems use one or more of these basic techniques to remove scale; wiping, brushing, scraping, peening and abrasion/erosion. These are often performed by pigging with various tools like a scrape, brushes or by the use of abrasive jets that cuts away the scale and leaves the tubing untouched.

In some cases when scale has completely blocked a well the only solution to making the well operational again is by full workover performed by a drilling rig.

2.4.2 Scale dissolver / chemical removal

Chemical removal is used to dissolve scale that has formed in the formation, in the near-wellbore region, in perforations, in tubulars, on downhole completion equipment, and in surface equipment. If scale is to be removed the normal practice is to firstly do a tube cleaning to remove oil and scale from the tubing. This is done to prevent the use of the scale dissolver on the way down to the affected area. Then dissolvers are pumped down to the scale affected area where they are left for some time to dissolve the scale. Scale dissolving is affected by temperature, higher temperatures increase dissolving abilities. (Statoil, 2011)

Chemical removal is performed with different solvents according to the type of scale (Schlumberger, 2013):

- Carbonate scales such as calcium carbonate or calcite [$CaCO_3$] can be readily dissolved with hydrochloric acid [HCl] at temperatures less than 250oF [121oC].
- Sulfate scales such as gypsum [$CaSO_4 \cdot 2H_2O$] or anhydrite [$CaSO_4$] can be readily dissolved using ethylenediamine tetraacetic acid (EDTA). The dissolution of barytine [$BaSO_4$] or strontianite [$SrSO_4$] is much more difficult.
- Chloride scales such as sodium chloride [NaCl] are easily dissolved with fresh water or weak acidic solutions, including HCl or acetic acid.
- Iron scales such as iron sulfide [FeS] or iron oxide [Fe_2O_3] can be dissolved using HCl with sequestering or reducing agents to avoid precipitation of by-products, for example iron hydroxides and elemental sulfur.
- Silica scales such as crystallized deposits of chalcedony or amorphous opal normally associated with steamflood projects can be dissolved with hydrofluoric acid [HF].

2.4.3 Scale inhibitor treatment

Scale inhibitors are chemicals that prevent or delay the formation of scale when added into reservoir water that normally produce scale. Scale inhibitor chemicals may be continuously injected downhole into the production system or periodically by scale squeeze operations. Very low dosages of these inhibitors can prevent scale precipitation. One of the main reasons for scale squeeze is that prevention is often more cost effective than removal. (Bai & Bai, 2010)

Some wells are equipped with equipment that leads scale inhibitor down the well where it can be injected into the well stream. The fluids will mix in with the well flow and prevent scale deposits in the production tubing, valves, pumps and production equipment. In the design phase of a new well there will be a need to address scale, so that if needed mitigation equipment can be installed. Since the inhibitor injection needs to be continuous, the normal practice is to have a dedicated line per well that is managed from the host facility.

Scale squeeze operations are performed to prevent scale in reservoir perforations and near wellbore. The operation is performed by stopping production and then pump chemicals into the well and out into the reservoir.

“Scale squeezing is performed by pumping chemicals from storage tanks onboard the vessel down into the well through dedicated injection point on the subsea manifold or Xmas tree. The injection point will include a check valve. The check valve will ensure that hydrocarbons cannot flow back onto the vessel should the pumps fail.” (Femsteinevik, 2008)

Shown in Figure 4 is a picture of an ROV connecting a Black Eagle hose to a subsea manifold during a scale operation. An illustration of how the connected IMR vessel pumps chemicals down the well and into the reservoir is described in Figure 5. A thorough program has been developed beforehand with regards to what chemicals are to be used.

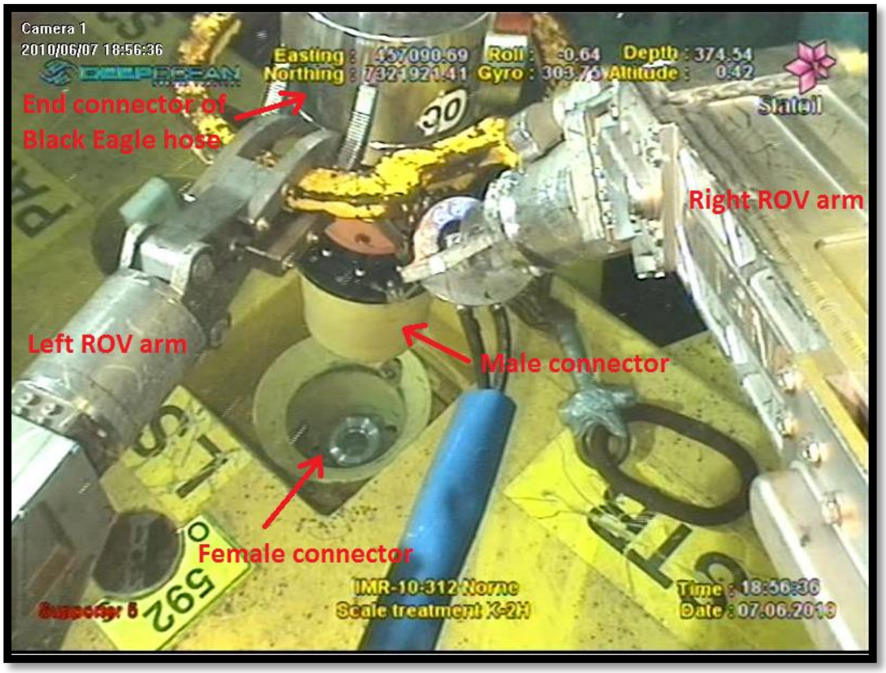

Figure 4 Picture of ROV attaching the Black Eagle hose to a subsea manifold (Statoil, 2010)

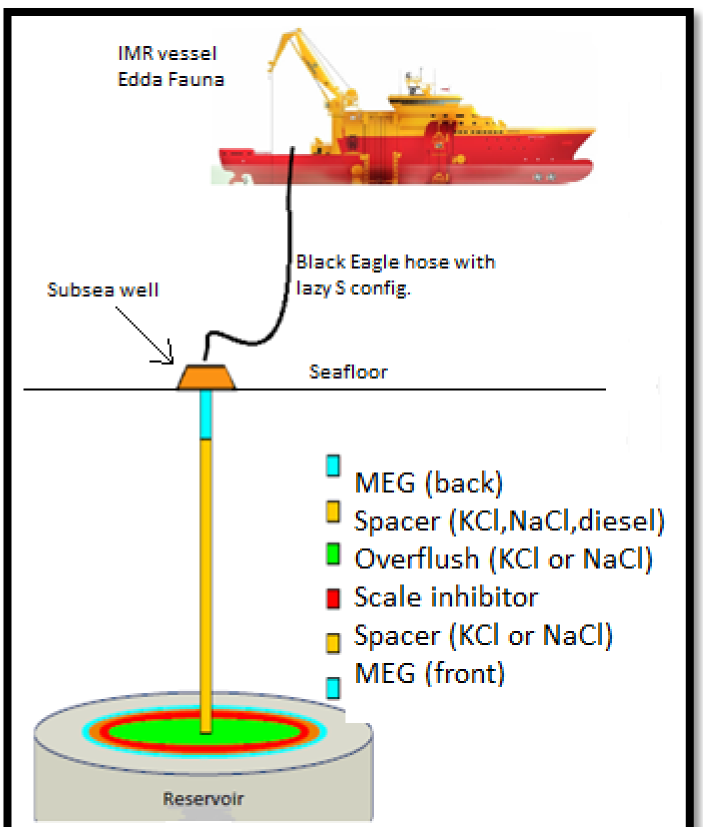

Figure 5 Illustration of scale inhibitor treatment of a reservoir (DeepOcean, 2008)

There are a range of chemicals used in scale squeeze operations depending on the reservoir and type of scale. Some chemicals are used solely to push the inhibitor chemicals into the right areas of the reservoir. The type and amount of chemicals are carefully calculated for each individual well. After the scale inhibitor chemicals are pumped into the reservoir the well is closed down for some time, normally from 6 to 24 hours, this is to let the chemicals sink into the formation and mix with the reservoir fluids. The desired effect of this treatment is to prevent scale from forming in the first place. Water passing through the formation will absorb some inhibitor and prevent scale depositions. The scale inhibitor mixed in the reservoir fluids protects against scale formation until the reservoir eventually runs out of inhibitor and there will be need for a new scale squeeze operation. Many factors contribute to the success of these operations and the length of the scale protection. (Unknown, 2013)

Some of the factors controlling the rate of scale inhibitor returns and effectiveness of squeeze treatment include (Unknown, 2013):

- Adsorption/desorption behavior of scale inhibitor on reservoir rocks and minerals.
- Precipitation of scale inhibitor in the reservoir.
- Other reasons for scale inhibitor entrapment in the reservoir.
- Modification of inhibitor properties by the porous media.

When selecting a scale inhibitor certain criteria are used in the selection process, samples and analyses of the well are used to determine the types of scale.

Some of the selection criteria for scale inhibitor include:

- Efficiency
- Stability
- Compatibility (not be affected by or interfere with other oil field chemicals)
- Type of scale (selection of scale inhibitor based on scale composition)
- Severity of scaling (effectiveness dependent on scaling rates)
- Cost
- Temperature
- pH
- Weather
- Application technique
- Viscosity

2.5 Historical development of scale management

Before in the oil and gas industry the majority of wells was dry wells located on fixed platforms. When scale started to precipitate in dry wells, this could result in decline in production and eventually lead to total blockage of the well. The practice was then to drill and re complete the well.

For the first subsea wells the same practice was applicable. But for a subsea well drilling had to be performed from expensive mobile drilling rigs, this was costly and time consuming work and for many wells found not beneficial, leading to abandonment of the well. The fear of possible scaling problems in oil and gas fields did in the past lead the selection of field development solutions to lean towards fixed platforms and fixed wells instead of utilizing subsea field developments.

With the increase in subsea wells and by the help of technology better ways to handle scale has been developed. Drilling samples give values of the substances present in the reservoir, these give indications towards future scaling problems. Measurements of the content of certain substances in produced water can determine types of scale and also show if scale is currently forming in the reservoir.

A very important part of scale management has been with chemical development. Some chemicals can remove scale from subsea pipes, valves and even the reservoir. While others, if injected into the reservoir can prevent scale from forming. By having knowledge of the types of scale present in a well, chemicals to best possibly remove and inhibit scale can be developed. The chemicals are constantly being improved so new and better chemicals are regularly entering the market. There is a big focus on scale chemical research, and recent research is focusing on developing environmental friendly chemicals with longer lasting effects.

The equipment used to pump chemicals down into the wells is also rapidly changing. In the past they had to mobilize entire scale system spreads onto an offshore vessel, which could take weeks to do. These systems consumed much space onboard the vessels and there was limited amounts of chemicals that could be brought onboard. This lead too many trips back to shore to resupply chemicals. Shown in Figure 6 is a scale squeeze setup on work deck for one of Statoil's scale operations previous to 2008.

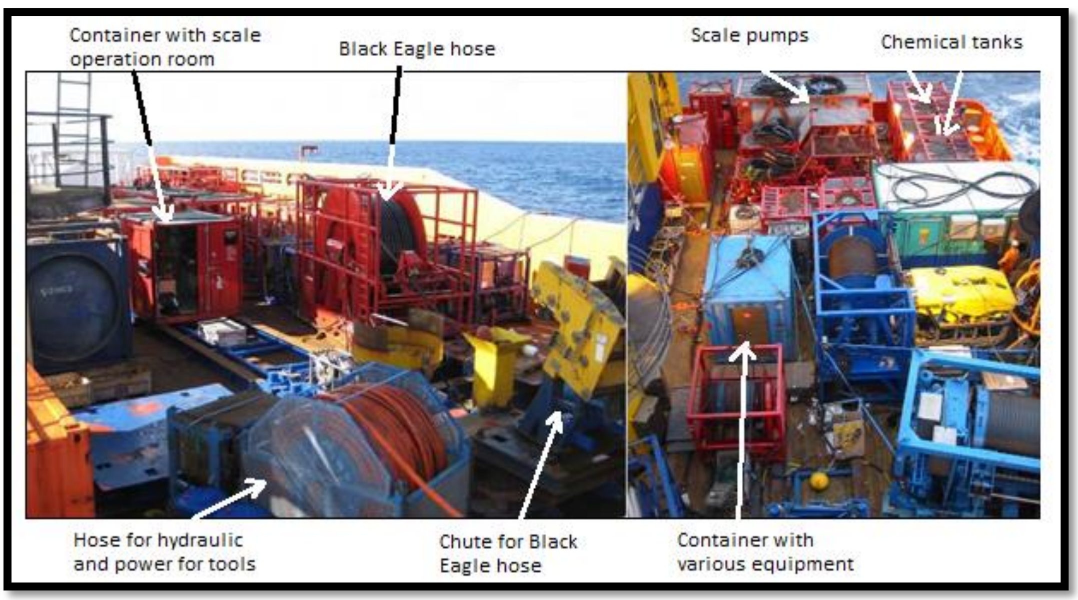

Figure 6 Entire scale system mobilized on deck of an IMR vessel (DeepOcean, 2008)

This has led to the arrival of specialized vessels into the market, which has internal scale systems that reduce mobilization to only a few days. These vessels have large internal tanks to store chemicals in. This gives them the opportunity to do several scale operations before having to resupply chemicals at shore. The technology onboard the vessels have also increased most procedures and almost all valve operations to be controlled from a work station in the operations rom, this reduces the need for personnel to manually operate equipment.

Edda Fauna was the first IMR vessel on contract with Statoil, it came into operation in 2008. The scale system had many minor problem areas and the system had to be overhauled and converted to become operational in a sufficient way. The utilization of this vessel has led to increased capabilities to perform scale operations and decreased time and money spent per operation greatly for Statoil. There are still potential to improve vessels and procedures to improve scale operations for the future.

The improvement of the space on the work deck from previous operations versus new operations can be seen in Figure 6 and Figure 7.

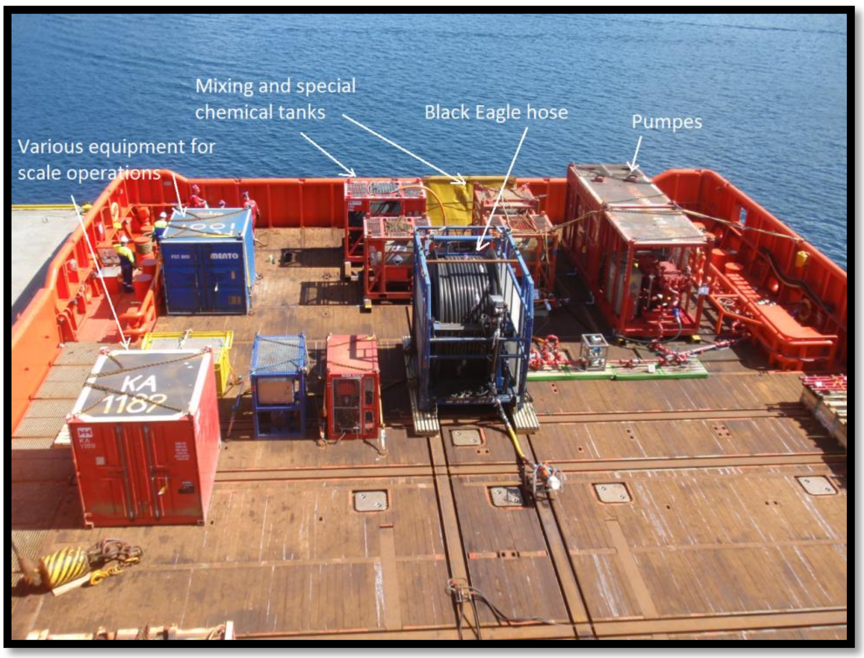

Figure 7 Work deck of Edda Fauna mobilized for scale operation in 2013

Vessels used for IMR operations have high day rates and the ability to perform operations quick and efficiently are therefore very important. Better vessels gives opportunities to execute scale operations on more wells, this can give a total increase in production.

2.6 Monohull vessel (Seven Viking)

There are two vessels on contract for Statoil which have the required systems to perform scale operations. Both vessels are state of the art IMR vessels with almost all the same capabilities. For simplicity only one of the vessels are described in detail in this thesis. The systems described for Seven Viking will be very similar to those onboard Edda Fauna.

Seven Viking is a new state of the art intervention vessel built by Ulsteinvik Shipyard in 2012 for Eidesvik and Subsea 7, a picture of Seven Viking is shown in Figure 8. From February 2013 Seven Viking has been on contract for Statoil's subsea IMR department. The vessel is designed to be able to handle several types of IMR operations. Seven Viking is equipped with an integrated scale treatment system to specialize the vessels capabilities for scale operations.

Scale operations are new to Subsea 7, and with the Seven Viking they aim to eventually enter the scale market. As for all new operations there will be need for knowledge and training in regards to scale and scale operations among Subsea 7's engineers and the personnel onboard the Seven Viking. It is desirable to have Seven Viking able to perform scale treatment operations as fast as possible. Statoil is planning to use Seven Viking for a scale treatment job during the autumn of 2013, to test the capabilities of the vessel and the crew.

Figure 8 Seven Viking (Subsea 7, 2013)

Seven Viking is equipped with a Dynamic Positioning system, the system will automatically keep the vessel in the required position during operations. The classification of the system is DP 2, which means the system has the safety feature of having total redundancy. Meaning it is equipped with 2 individual systems, if one system fails the other takes over.

General data for Seven Viking (www.subsea7.com, 2012):

- Length 106.5m x breadth moulded 24.5m
- Service Speed: 16.0 knots
- Accommodation: 90 persons
- AHC Offshore crane: 135 Te @ 13m
- 2 x Workclass ROVs
- 1 x Observation class ROV

2.6.1 Work deck and Hangar

On Seven Viking there is 850 m^2 of flat unobstructed work deck, shown in Figure 9 is an overview of the main deck with the most important features pointed out. The bulwark is 1.3 m and in the lifting zone it is possible to detach and remove 15 m of it. The deck is made up of wood and has integrated T-bars for seafastening, the T-bars will reduce impact loads and strengthen welds for seafastening. There are 65 integrated D-link rings for fast and easy seafastening. The deck is also equipped with container locks for 8 containers.

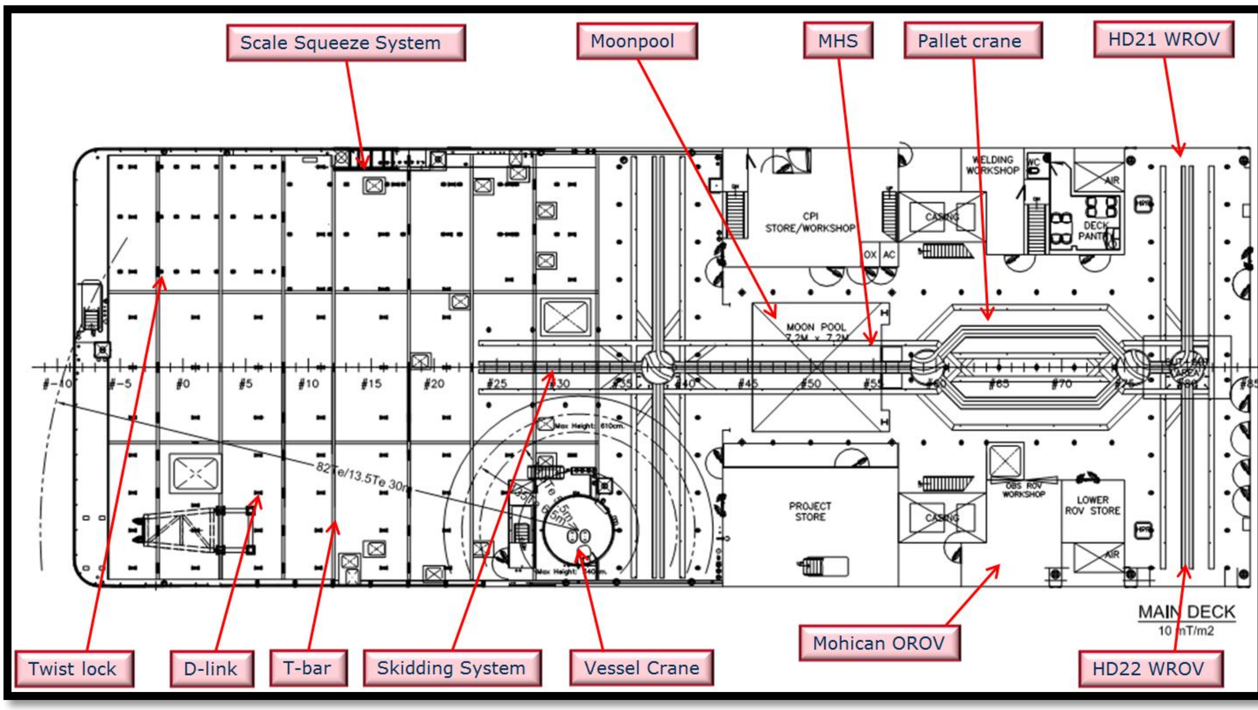

Figure 9 The main deck on Seven Viking (Subsea 7, 2013)

A skidding system is integrated in the deck, this provides an easy way of moving equipment around. The skidding system has a max capacity of 70 Te on a 6x6 m pallet and 30 Te on a 3x3 m pallet.

The Seven Viking is equipped with a large indoor hangar which contains ROV's, moonpool and Module Handling System (MHS). It is a big advantage to be able to work and perform operations indoor. It also contains storage rooms for equipment and areas with sufficient utility equipment for doing light repairs on the various tools. The moonpool (Figure 10) is 7.2x7.2 m and is capable of launching modules up to 6x6 m. The top hatch in closed position is able to withstand loads from modules being skidded across it. In the moonpool there is a dampening system to minimize slamming loads, water splashing and noise during operations. For scale operations the Black Eagle Hose can be deployed through the center hatch to minimize moonpool opening.

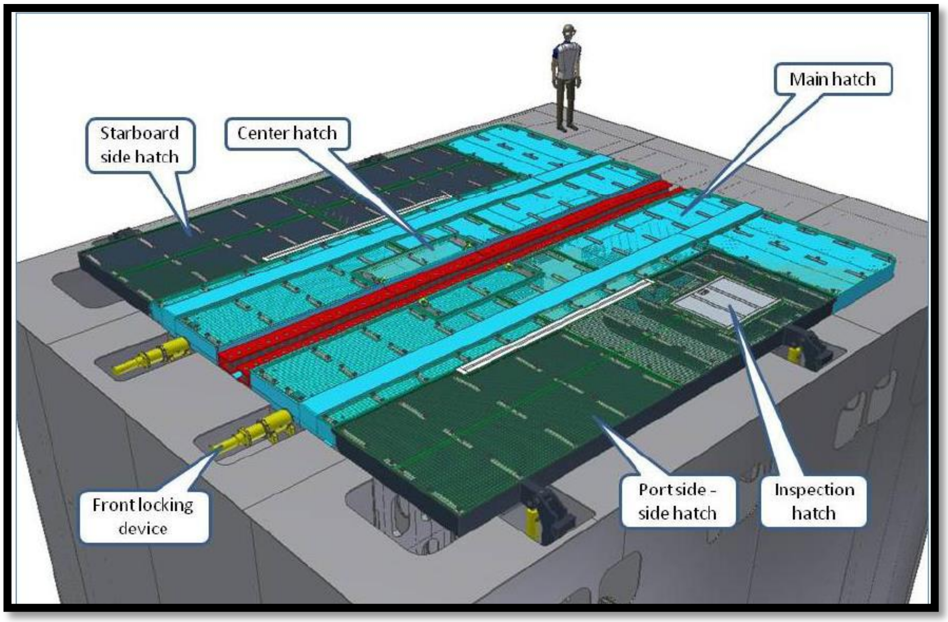

Figure 10 Moonpool in Seven Viking Hangar (Subsea 7, 2013)

The MHS is fully integrated in the hangar and has a cursor system for controlled launch and recovery of modules. The MHS is capable of lifting up to 70 Te to a height of 10 m, it can be operated in conditions up to 5 m HS and down to depths of 2000 m.

2.6.2 Remotely Operated Vehicle (ROV)

The vessel is equipped with two working class ROV's (WROV's) (as shown in Figure 11), and one observation class ROV (OBSROV). All ROV systems have optical fiber communication to the vessel and redundant power supply. The ROV's are electrical with a hydraulic power unit to operate all the ROV tools. The ROV's can be launched, retrieved and are able to operate in up to 5 m HS.

Figure 11 Working class ROV (Subsea 7, 2013)

2.6.3 Scale Treatment System

The Seven Viking has the class notification of Well Stimulation Vessel and Low Flashpoint Liquid (LFL*). Required for this is gas group IIA and temperature class T3. The vessel has to meet strict requirements to bring certain chemicals onboard, requirements for the different chemicals is listed in the International Bulk Chemical (IBC) code chapter 17. The chemicals onboard have to be checked against gas/temp class and towards all other brought chemicals. The Scale Treatment control system is located in and operated from the operations room in the vessel.

The main components in the Scale Treatment System for Seven Viking are listed in Table 4. Operations room, SCTR room and special chemical tanks are located similarly as shown in Figure 12, which is an illustration of Edda Fauna.

Table 4 Main components of the scale system and their objectives

Number	Component	Objective
1	Cargo pumps placed in safe zone on work deck	Act as booster pumps towards Scale Treatment System
2	Deck tanks, on work deck	LFL/LFL* liquids are not allowed to be discharged from Safe Zone pump room directly to LFL* SCTR pump room
3	Booster pumps, SCTR room	Act as booster pumps towards Scale Treatment System
4	Special Product LFL* pumps 5 pcs. Placed in cofferdam	Act as booster pumps towards Scale Treatment System, in parallel with Booster pumps
5	Special Product Dosing pumps	Act as dosing pumps for chemicals that are added into the main flow coming from either Booster pumps or Special Product pumps
6	Filter cartridges for Scale Treatment system, in SCTR room	Removes particles and cleans chemicals to meet required quality
7	Heater for Scale Treatment system, in SCTR room	Used to heat chemicals to desired temperature before injection
8	Scale Treatment pump type DP212 (shown in Figure 13), in SCTR room	Primary pumps used to discharge chemicals at high pressure 345 barg delta p, and total of 2800 l/min downstream towards Subsea modules
9	RFO pump type MTM7T, in SCTR room	Used for discharge of FW, SW and MEG/Brine subsea, for use in Ready For Operation (RFO) work
10	Min flow circuit, with Min flow valve, flowmeter and cooler, in SCTR room	Control that min flow is upheld, min flow circuit is able to lead the remaining flow back to the suction side of the pump again, cooler to remove heat energy
11	Slop tanks and Slop pumps	Used to clean the Scale Treatment System, MEG is used to flush the pipe and pumps completely, eventually the slop is filled into the slop tank
12	Spool Piece if Deck tank is not used	To be used if Deck tank is disconnected/removed
13	Flow meters for all pumps, in SCTR room	To keep control of fluid flow
14	PG Mixing Agitators, in SCTR room	Used for mixing the chemicals which are used in the Scale Treatment System

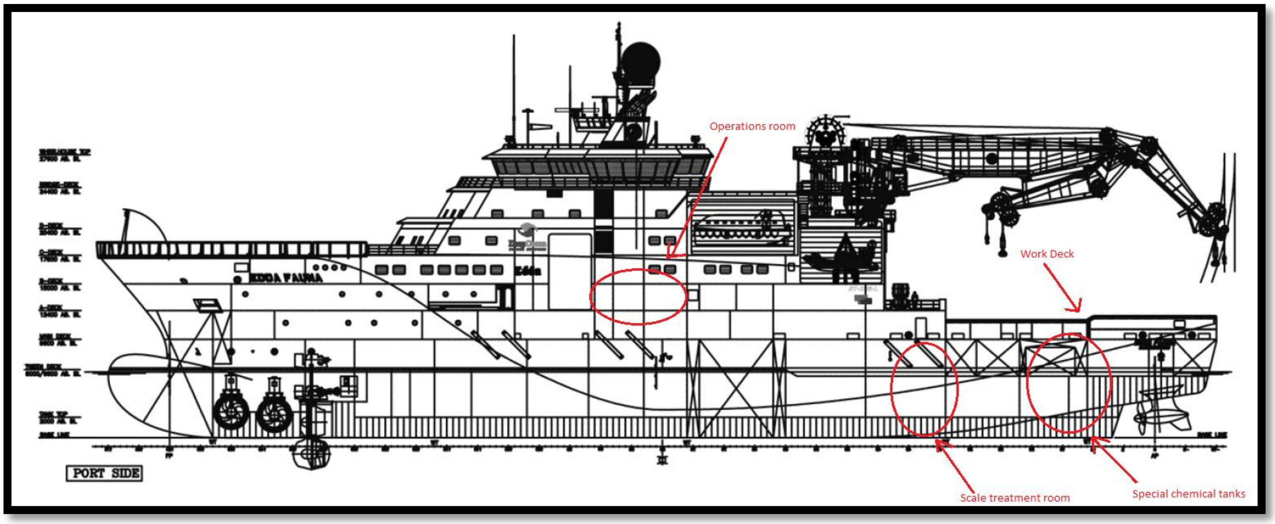

Figure 12 Edda Fauna with referrals to placement of scale system

Figure 13 Scale Treatment pump type DP212 (PG Marine Group, 2012)

2.6.4 Black Eagle hose

The Black Eagle hose system is not permanently installed onboard the IMR vessels, it is mobilized for scale operations only. Statoil does not own this equipment and it must therefore be rented by a third party for the timespan of the operation.

The Black Eagle hoses is designed for use in the oilfield and consists of a series of multi-spiral wire inforced hoses. They have good resistance towards chemicals and can also be used to pump cement and gasses. An illustration of a Black Eagle hose is shown in Figure 14.

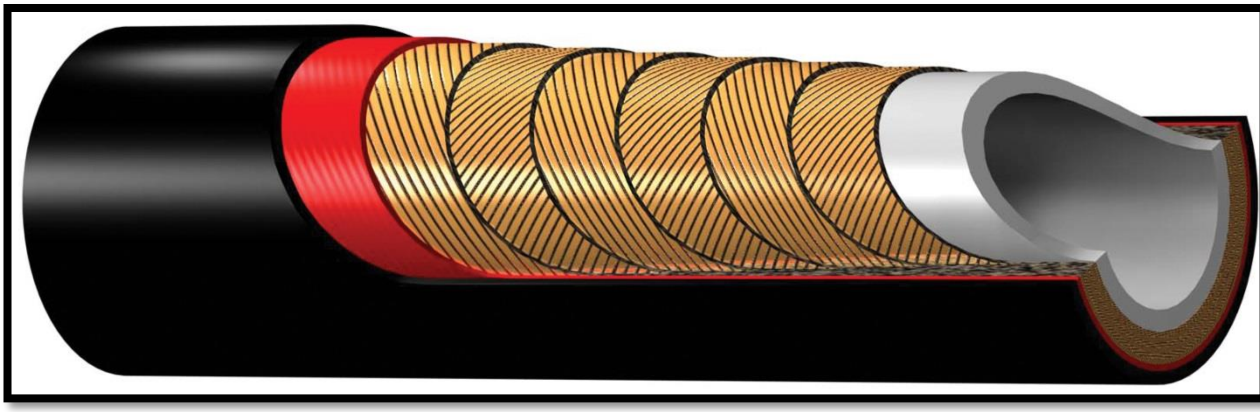

Figure 14 Cut section of a Black Eagle hose (Parker Hannifin, 2010)

General data on Parker's Black Eagle Hoses (Parker Hannifin, 2010):

- Working pressure from 5,000 psi (345 bar) up to 15,000 psi (1035 bar)
- COLORGARD, dual colour safety feature with extra thick cover for superior abrasion resistance
- Long continuous lengths, no splicing – up to 9800 ft (3000 m)
- Polyamide (PA11) core tube and Fluorpolymer technology for cleanliness
- Temperature up to 158 ° F (70 ° C), short term 125 ° C
- Smaller OD than flexible pipe allows for more hose per reel
- Excellent chemical resistance providing long service life

Shown in Table 5 is specific data for various Parker Black Eagle Hoses.

Table 5 Overview of Black Eagle Hoses produced by Parker Hannifin (Parker Hannifin, 2010)

Part Number	Inner Diameter (ID)		Outer Diameter (OD)	Working pressure	Burst pressure	Max. length	Weight	Collapse pressure
	size DN	inch mm	inch mm	psi MPa	psi MPa	ft m	lbs/ft kg/m	psi MPa
2640N-16V80	-16 25	1 26.0	1.57 40.0	15,000 103.5	43,500 300.0	5,900 1,800	1.95 2.90	1,200 8.0
2640N-24V80	-24 40	1 ½ 38.0	2.76 70.0	10,000 69.0	33,350 230.0	4,900 1,500	4.85 7.20	950 6.5
2580N-32V80	-32 50	2 50.5	3.31 84.0	10,000 69.0	25,000 172.5	1,970 600	6.31 9.40	826 5.7
2440N-48V80	-48 78	3 75	4.80 122	10,000 69.0	25,000 172.5	1,476 450	12.5 18.60	580 4.0
2640N-48V80	-48 78	3 75	5.12 130.0	15,000 103.5	33,750 233.0	1,300 400	18.5 27.50	1,160 8.0

2.6.5 Types of Scale Operations

Types of scale treatments Seven Viking is designed to perform (Finseth, 2012):

1. Tube cleaning - To wash the tubing for oil film and scale. This is often used ahead of a scale dissolver jobs to prevent the dissolver to be spent before reaching the reservoir.
2. Scale dissolver - Used to dissolve scale in production tubing, valves, perforations and reservoir if scale is indicated in the well. Scale dissolver will be pumped into the pipes and/or reservoir, the well will then be shut in for some time before being flowed back to the production platform.
    a. BSV cleaning - Heated scale dissolver is used to dissolve scale in the downhole safety valve (BSV). The ability to dissolve scale increases with temperature. The chemicals are pumped slowly over the BSV.
3. Scale inhibitor - Scale inhibitor is used to prevent or delay the scale from precipitating. Scale inhibitor is pumped down the well and into the reservoir, the well will be shut down and the chemicals left in the reservoir for an appropriate amount of time, before the well will start up production again.

2.7 Participants of a scale operation

For all petroleum exploration and production companies, scale related issues are normal and a good scale management strategy is very important. To be able to handle scale issues it is common to cooperate with service companies towards finding good solutions for handling of the scale problems.

To perform scale treatment operations there will be a need for certain basics:

- To have well equipped vessels capable of these kind of operations
- Mobilization of extra non-standard vessel equipment
- Chemicals to be used in operations
- Personnel to man the vessel and oversee operations

The IMR vessels used by Statoil for scale operations are provided by DeepOcean and Subsea 7. DeepOcean has performed several scale operations with Edda Fauna, an IMR vessel equipped with an internal scale treatment system. Subsea 7 is now entering this market with the acquiring of Seven Viking which also has an internal scale treatment system. DeepOcean has much experience from scale operations whereas Subsea 7 is new to these types of operations.

When scale operations are planed there will be a need for equipment to be mobilized, the right kinds of connections to match subsea equipment, pumps, tanks, hoses, valves and chemicals.

The subsea connection point for the scale treatment system needs an interface to adjust for the different solutions of subsea equipment, this is provided by the equipment manufacturing companies in the oil and gas industry.

There are several companies producing chemicals for scale treatment and prevention. All chemicals used in scale operations needs to be approved, the approved chemicals are listed in chapter 17 of the IBC code.

Some of the companies that are involved in Statoil scale operations include:

- Edda Fauna - DeepOcean / Østensjø
- Seven Viking - Subsea 7 / Eidesvik
- Equipment, chemicals, operation - Halliburton
- Subsea equipment - Aker Solutions
- Subsea equipment - FMC Technologies
- Chemicals - Nalco
- Chemicals - Champion Technologies

2.8 Description of a normal scale operation on Edda Fauna

Described here are procedures regarding scale operations for Statoil IMR.

2.8.1 Mobilization

During mobilization all necessary equipment and chemicals are to be loaded onto the vessel. Equipment will be safely seafastened, and chemicals stored in appropriate tanks.

Halliburton will mobilize a spread of pumps, tanks, hoses, valves and connections, including the Black Eagle hose system. This equipment will be connected to the vessel tanks and pumps, and together the system will be able to store and pump chemicals from vessel tanks and deck tanks down and into the well via a subsea manifold.

Depending on connection point an External Tree Cap (ETC) might be needed, this is supplied by the subsea equipment manufacturer with a connection point to the Black Eagle hose system. Tools for installation of ETC will also be brought onboard. The ETC and ETC running tool (ETCRT) is shown in Figure 15.

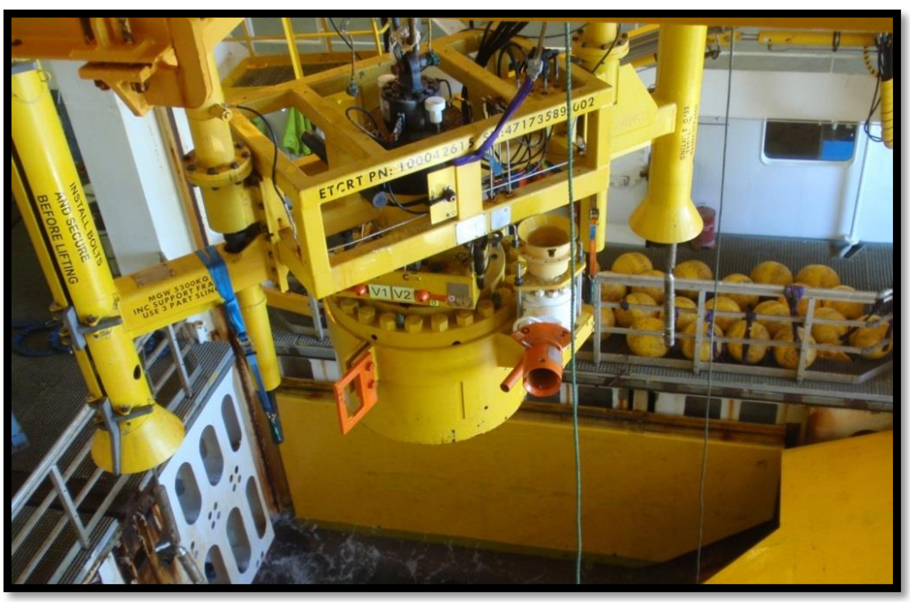

Figure 15 The ETC and ETCRT being lowered down into the moonpool

Chemicals for the scale treatment operation will be mobilized according to pump program for the specific job or jobs that are to be performed.

2.8.2 Offshore scale operation with connection to manifold

A step by step description of a scale operation performed on Edda Fauna in June 2013 is shown in Table 6.

Table 6 Description of a scale operation

Step	Performed task	Usual time consumption
1	The IMR vessel will firstly transit to location and by permission from the production platform set up on Dynamic Positioning (DP) above the well that is to be treated.	N/A
2	Control of the well will not be given to the vessel, this will always remain in the control of the personnel in the Central Control Room (CCR) on the production platform.	N/A
3	By dialog between the vessel and the CCR actions are taken to shut down the given well, put up necessary barriers and secure that the well is ready for the operation.	N/A
4	An ROV will open a hatch on the protective structure around the manifold, this is to gain access for the connection of the ETC and the Black Eagle hose.	1 hour
5	The ETC will be organized on the vessel, connected to the MHS and lowered down onto the manifold on guidelines, an ROV will operate the necessary tools to properly fasten the ETC. The ETC and ETCRT is shown in Figure 15. Guidelines will be retrieved to the vessel.	2-3 hours
6	According to the work program a number of valves will be operated locally by an ROV.	N/A
7	ROV personnel will maneuver a ROV into position close to the manifold and use ROV tools to operate valves into the acquired positions.	1-2 hours
8	The Black Eagle hose is located on a winch reel at the back of the work deck. It has a long free span forward of 31 m where it is connect atop a chute, it will then continue down the moonpool and into the sea.	N/A
9	Prior to hose launch the Black Eagle hose is filled with MEG and pressurized to 200 bars to increase the stiffness of the hose.	15-30 minutes
10	During deployment and recovery of the Black Eagle hose a Dead Man Anchor (DMA) weighing 750 kg is attached, this is to counter the buoyancy forces from attached buoyancy modules and to keep the Black Eagle hose straight during descent and retrieval.	N/A
11	When deployment of the hose has commenced buoyancy modules will be attached to the first 80 m of the Black Eagle hose, these buoys will aid in the creation of a lazy S configuration of the Black Eagle hose.	1 hour

Step	Performed task	Usual time consumption
12	The lazy S configuration will reduce loads from vessel motions on the Black Eagle hose during chemical pumping. The lazy S configuration will also provide a possibility for drift off, if troubles appear the vessel can drift off approximately 150 – 200 m where it can try to fix the situation, if not the Black Eagle hose has to be cut off at the chute.	N/A
13	The winch on the Black Eagle hose is operated locally on work deck. The hose will be run all the way down to the seabed where the DMA is landed, at some distance from the manifold.	0.5 hours
14	An ROV will detach the DMA from the Black Eagle hose and grab the end of the now vertical hose.	N/A
15	The ROV will first create a lazy S configuration on the hose before attaching it to the ETC on the manifold. The setup of the lazy S configuration used for scale operations is illustrated in Figure 16.	0.5 hours
16	When the ROV has connected the Black Eagle hose to the ETC, the connection will be tested. Firstly a low pressure test followed by a high pressure test. The pressures will be monitored in the vessel operations room and the ROV will visually inspect the connection.	1 hour
17	If both tests are approved contact with CCR will be established and the valves down into the well opened. This will create direct access from the Black Eagle hose into to the well and pumping of chemicals can commence.	0.5 hours
18	Depending on the scope of the operation, various chemicals will be used to flush, remove and inhibit scale.	4-24 hours
19	A pump program is designed for each individual well, and this will give a detailed description of the given procedures to be performed and chemicals to be pumped. An example of a pump program for scale inhibition pumping is shown in Table 7.	N/A
20	There are normally 3 different procedures that can be performed depending on the necessities of the well. Tube cleaning, scale dissolver and scale inhibitor, these are described in chapter 2.6.5 Types of Scale Operations.	N/A
21	When all the pumping is finished the vessel will retrieve the Black Eagle hose and the ETC. Guidelines and guideposts will be retrieved and the protection structure hatch closed. An ROV survey of the area will be performed to make sure that everything is as should be. The vessel will then move on to its next job.	Reversed previous procedure

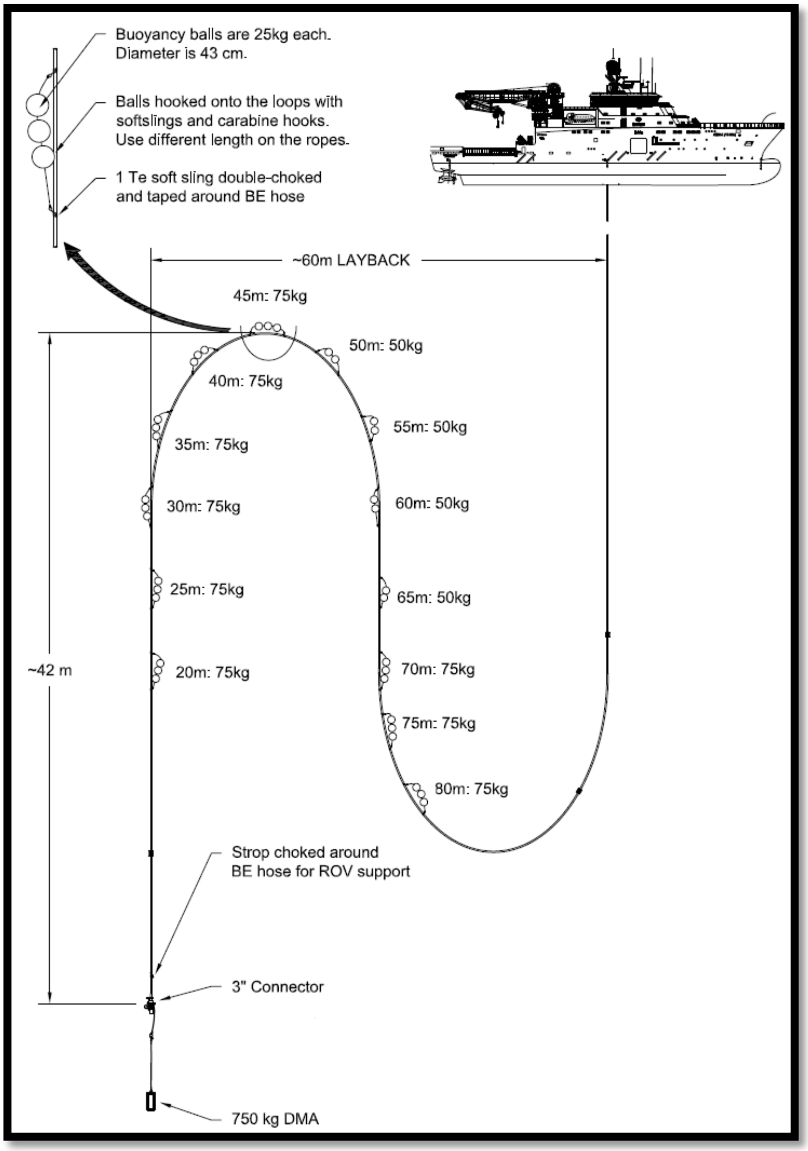

Figure 16 Scale treatment Black Eagle buoyancy & markup layout from Edda Fauna (DeepOcean, 2013)

Table 7 Chemical part of a pump program for a scale inhibitor operation

Step	Chemical	Volume	Accumulated volume
1	Diesel	5 m^3	5 m^3
2	0,5% EC6660A in SW Preflush	100 m^3	105 m^3
3	10% EC6660A in SW Main treatment	300 m^3	405 m^3
4	0,5% EC6660A in SW Over flush	500 m^3	905 m^3
5	0,5% EC6660A in SW Tubing volume	61,3 m^3	966,3 m^3
6	MEG Riser placement	4 m^3	970,3 m^3

3. Challenges regarding equipment and procedures

Described here is equipment and procedures that are considered to be non-optimal.

The topics described here are based on experiences from:

- Study into scale and scale management
- Study of Statoil's previous scale "End of Job Reports" and "Experience Transfer documentation"
- Offshore trip, participating as an observer during scale operations onboard Edda Fauna
- Discussions with the crew onboard Edda Fauna
- Discussions with Statoil personnel

There are many aspects of scale operations that have minor difficulties or can be considered non-optimal, including:

- Scale treatment system onboard the vessels
  - Pipes and hoses
  - Valves
  - Cleaning system
- ETC and ETCRT used for some operations
  - Weather criteria of 4 m Hs for launch and recovery
- Equipment needed for some operations
  - Old and in need of upgrades
- **Black Eagle hose system**
  - Flow rate
  - Placement
    - Launch and recovery
  - Winch system
  - High rental prices
  - Buoyancy system
  - Connections
- Chemicals, and desires for improving chemical properties
  - Viscosity of certain chemicals
  - PH values of some chemicals
  - Inhibitors ability to last longer
  - Ability to place chemicals in desired areas of a well
  - Environmental friendliness of the chemicals

Considering all these non-optimal areas the focus of this thesis has been narrowed down to investigate the challenges regarding the Black Eagle hose system. It was decided during discussions with Statoil to focus on these challenges. The system for the Black Eagle hose is regarded by personnel working with it to have great potential for improvements. It was therefore desirable to have an investigation into the Black Eagle hose system, as it is believed that an upgrade of this system can lead to large improvements for the scale treatment system and scale operations in general.

3.1 Flow rate through a 2" Black Eagle hose

The flexibility of the hose and the small diameter leads to a maximum flow rate of 1200 l/min. When large volumes of inhibitor chemicals are to be pumped at this flow rate the pumping takes long time. In most cases when pumping scale inhibitor the limitations to the flow rate that can be pumped into the reservoir is never reached.

Thus for many scale operations a larger flow rate could be possible and would lead to a reduced number of hours spent pumping chemicals.

3.2 Placement of Black Eagle hose system

The Black Eagle hose is on a big reel with an attached winch system, the reel is placed far back on the work deck where it is properly seafastened. The hose is stretched in a free span of 31 m from the reel forward onto a chute which then leads it down the moonpool and to the sea bottom, this set-up is shown in Figure 17. When launching the hose it is pressurized with 200 bars to keep it rigid, and a weight of 750 kg is attached to the hose end to weigh it down.

Figure 17 Black Eagle hose coming from reel and onto chute and down into moonpool

Having the Black Eagle hose in this position, with the long free span between reel and chute makes it impossible to use either constant tension or heave compensation systems to reduce loads on the hose.

Some of the challenges related to the Black Eagle hose placement include:

- Large loads on Black Eagle hose during deployment and recovery, especially in bad weather.
- Large wear and tear on the hose.
- Operational limit of 4 m Hs for the Black Eagle hose system.
- Waiting on weather and thus monetary losses when Hs are between 4 – 5 m.
- Not possible to use constant tension system.
- Not possible to use heave compensation system.
- This setup uses much space on work deck.

Upgrading the Black Eagle hose system and moving it to another location on the vessel can be a huge improvement to scale operations, both in respect to operational limit and time consumption.

3.3 Winch system for Black Eagle reel

The Black Eagle hose is on a reel with an attached hydraulic winch system. The winch system, if used correctly, is capable of winching the Black Eagle hose up and down during hose deployment and recovery. A winch system with a Black Eagle hose on similar to the systems used on the IMR vessels is shown in Figure 18.

Figure 18 Picture of Black Eagle hose on a reel with a winch system (Offshore Magazine, 2011)

Some of the main challenges of the winch system include:

- Needs to be operated manually on work deck
- Operator has to steer both reeling speed and the spooling device simultaneously
- Constant tension and heave compensation systems cannot be used

Based on the fact that the operator must simultaneously control the reeling speed and the spooling device guiding the hose onto the reel, the winching has to be performed with skill and focus from qualified personnel. There are previous incidents where errors from the operator has led to damages on the Black Eagle hose and even ruined the hose.

A more advanced system could simplify the winching and lead to increased lifespan of the Black Eagle hose.

3.4 High rental prices for Black Eagle hose

The Black Eagle hose system including the hydraulic winch is essential to scale operations as it provides the connection between vessel and subsea wells. When performing scale operations Statoil rents this equipment at high day rates. A roughly estimated day rate is 50 000 NOK.

In the long run the purchase of a Black Eagle hose when also accounting for required maintenance is believed to quickly outweigh the costs of renting.

3.5 Launch of current Black Eagle hose buoyancy system

During Black Eagle hose deployment, buoys are fitted onto the lower part of the hose, approximately the first 80 m of hose. The buoys are going to create a lazy S wave configuration to remove loads from vessel movement during the operation. The setup of the lazy S configuration with the buoy system is shown in Figure 16. During launch and recovery of the hose, the winch operator has to make stops so that personnel can manually attach or detach buoys to required positions on the hose. Attachment of buoys is shown in Figure 19. The total time it takes to launch and lower the Black Eagle hose down to the seabed, set up the lazy S configuration and connect the hose to the subsea well is usually 1.5 hours. The time aspect for hose recovery is much the same. The buoy system is cause for much of the time spent for hose launch and recovery.

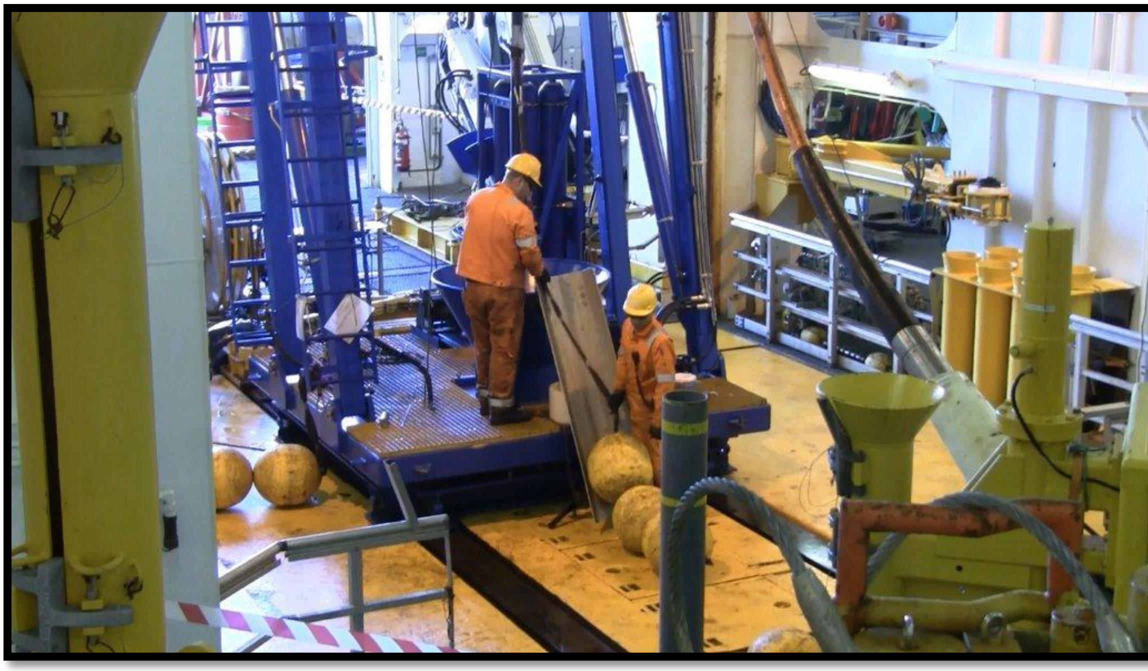

Figure 19 Attachment of buoys to Black Eagle hose (Statoil, 2012)

A fixed buoyancy system onto the Black Eagle hose could lead to a big reduction in operational time consumption.

3.6 Connection between vessel tanks and Black Eagle hose

Between the on deck connection point for the vessel tanks and the Black Eagle hose a large spread of valves are mounted together. This is also where the connection from tanks located on work deck onto the scale pumping spread takes place. Some measuring gauges and equipment is attached to give feedback to the onboard personnel. This system of valves is gathered together each mobilization and can be a bit different depending on what equipment is brought onboard. There are sometimes issues during mobilization due to missing or non-functional valves, this can sometimes lead to delays. A typical assembly is shown in Figure 20.

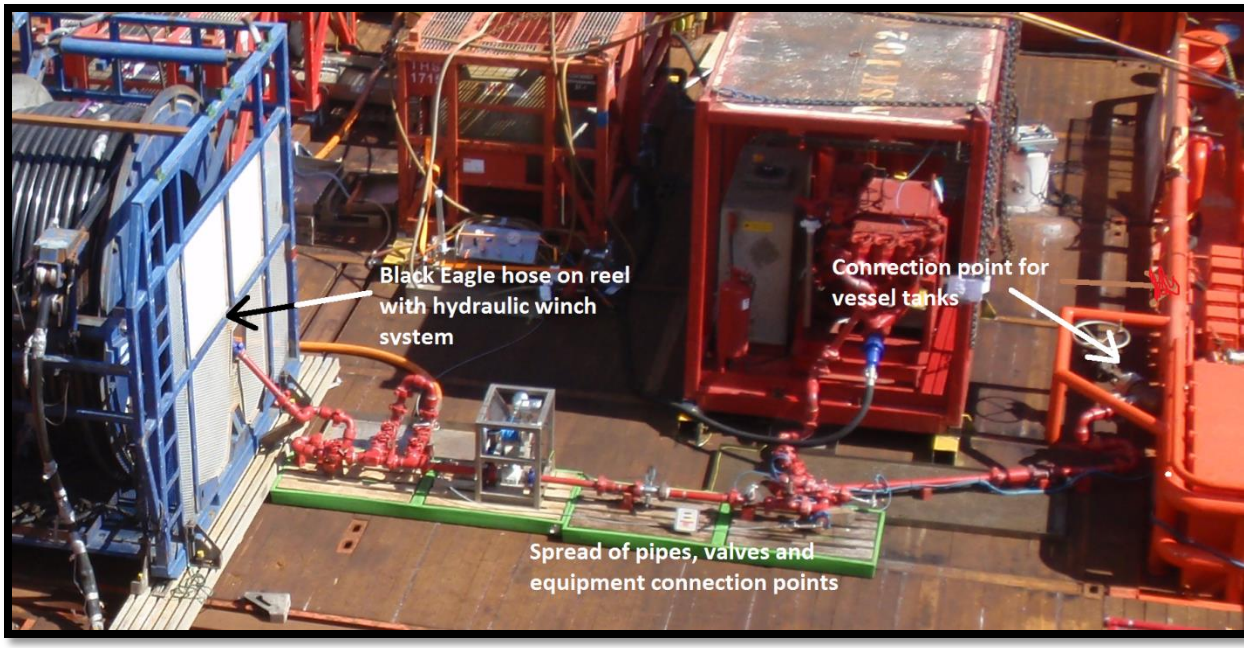

Figure 20 Pipes and valves connecting vessel tanks and Black Eagle hose

By having a fixed spread of valves where it is possible to block of the valves not being used during an operation can lead to easier and faster mobilization and fewer slip-ups during mobilization.

3.7 Overview of the studied challenges

After studying the scale systems and by discussion with Statoil it was found desirable to look deeper into the system regarding the Black Eagle hose. The overall challenges of the Black Eagle hose system can be broken down into six main challenges, these are thoroughly described in chapter 3.1 to 3.6.

It can be seen that most of the challenges are linked in some way and that some solutions can result in solving several of the challenges simultaneously. This is further investigated and discussed in the upcoming chapters.

4. Improvement ideas

This chapter contains suggestions towards improvements to equipment and procedures regarding scale operations. The improvement ideas are based on the challenging topics described in chapter 3. After the investigation into the challenges regarding the Black Eagle hose system these possible improvement ideas was produced. The ideas described in this chapter are meant to be a draft for Statoil to consider and use for further development.

The solutions investigated and described in this thesis include:

- Increased flow capacity
- Improved permanently installed Black Eagle hose system
    - New placement
    - Improved winch system
    - Owning the Black Eagle hose system instead of renting it
- Permanently installed buoyancy system

4.1 Upgrade of flow Capacity (2” vs 3” Black Eagle hose)

A possible solution to improve pumping during scale operations is to increase hose diameter, this can lead to higher flow rates and reduce operations time. The proposed solution is to upgrade the 2” Black Eagle hose to a 3” Black Eagle hose.

To assess the benefits of the upgrade, calculations about potential flow capacity is performed. The calculations are based on scale operations data from the previous three years. Focus will be on finding the potential for saving time during scale pumping.

Benefits of upgrading to a 3” Black Eagle hose:

- Faster scale operations
- Larger variation of flow capacity
- Cheaper scale operations
- Possibilities to perform more scale operations
- Improved recovery

A 3” Black Eagle hose will be much bigger and heavier than a 2” hose and use more space, a larger reel and winch system will also be required.

Parker, the manufacturer of Black Eagle hoses delivers hoses with up to 3” inner diameter. The length of the Black Eagle hose needed for Statoil scale operations, will be in the range of 550 m to 750 m. Having a continuous length Black Eagle hose is very practical and desirable for scale operations. The production of continuous length Black Eagle hoses is a tricky process, and is related to the diameter of the hose, a larger diameter increases production difficulties. Parker cannot deliver continuous length of 3” hoses for these required lengths, so splicing of two hoses will be necessary. The limit for continuous 3” hoses is around 350 m.

The splicing of two hoses will result in a joint on the Black Eagle hose system, this can lead to several undesirable issues:

- Larger possibilities for leaks
- Takes more space on the reel
- Increase difficulties with reeling
- Increased difficulties with spooling onto reel

This proposed solution of using a 3” Black Eagle hose for scale operations can be combined with the other improvement ideas in this thesis.

4.2 Improved permanently installed Black Eagle hose system

A solution to improve operations is to upgrade to a permanently installed Black Eagle hose system with certain upgrades like; new placement and constant tension and heave compensation systems. There are numerous aspects to investigate for optimization of this system, only an outline of the proposed system is described in this thesis.

The new Black Eagle hose system will be placed on upper deck such that the hose can be run straight down into the moonpool, an illustration showing the placement is shown in Figure 21. The placement of the reel is central to the functionality of support systems such as constant tension and heave compensation. In today’s practice the long free span of 31 m from the reel to the chute hinders the use of constant tension and active heave compensation.

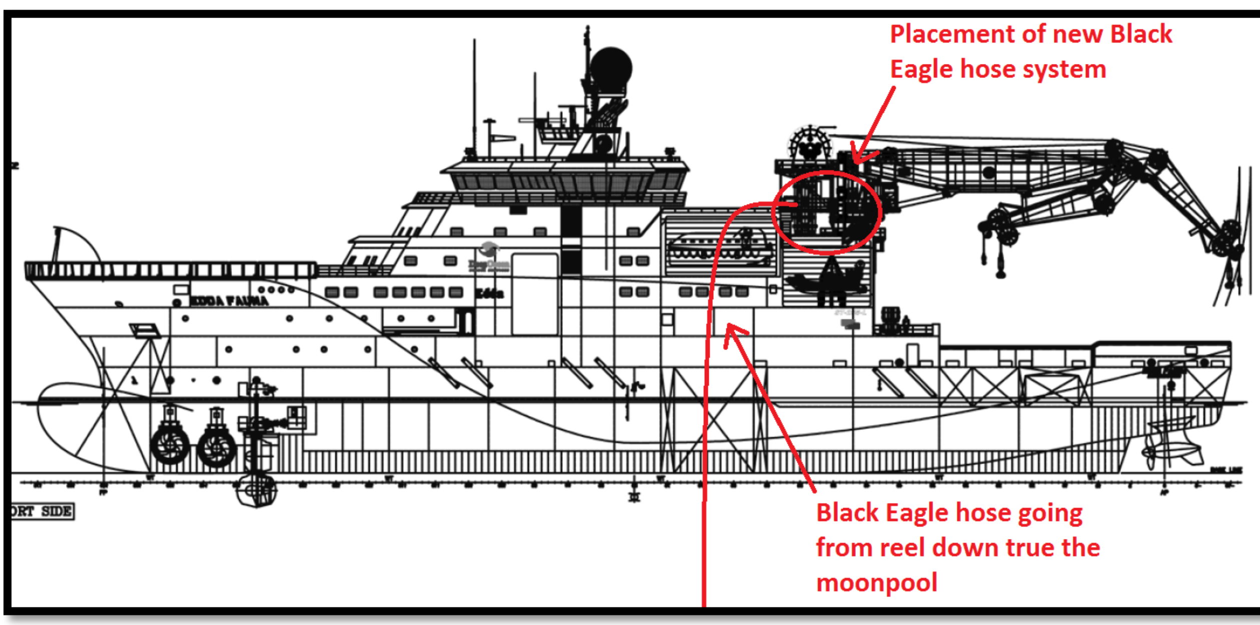

Figure 21 Placement of new Black Eagle hose system shown on Edda Fauna

The Black Eagle hose will be on a reel with an advanced winch system. The winch system will have two motors this to give some redundancy to the system. There will also be installed systems for both constant tension and active heave compensation. The constant tension system will control that the force set on the Black Eagle hose during launch and recovery remains constant. The active heave compensation system will counter the movements of the vessel, such that the Black Eagle hose is not affected by the weather conditions. The installation and use of these systems will greatly reduce the forces on the Black Eagle hose and can increase the hose lifetime. This can lead to an increase in the operational window for scale operations, being able to operate in up to 5 m Hs will reduce vessel time spent waiting on weather.

Shown in Figure 22 is the reel and winch system for the cable providing hydraulic fluids and power to the various tools used on Edda Fauna, the cable system has constant tension and heave compensation. The new Black Eagle hose system will be a similar system and most likely be placed on top of this system.

Figure 22 Cable system for running tools

The winch system will be controlled from the operations room through hardwiring and a possibility to run the winch locally on the upper deck will remain.

The installation of this system can lead to several pros including:

- Reduced mobilization time
- Reduced waiting on weather
- Active heave compensation and constant tension
- Reduced loads on the Black Eagle hose
- The Black Eagle hose will have an improved lifespan
- The Black Eagle hose winch can be controlled both from operations room and manually on the reel
- Possibly cheaper to own and maintain than to rent at high costs

The current practice on Edda Fauna is to use a 2” Black Eagle Hose with a hydraulic winch when performing scale operations. This hose system is rented and mobilized for every scale campaign, the renting cost is approximately 50,000 NOK/day.

4.3 Permanently installed buoyancy system

The attachment of buoys is contributing to the long deployment time for the hose, hose deployment takes approximately 1.5 hours. By having a buoyancy system permanently installed on the hose the deployment time can be reduced to about 0.5 hours. The same goes for hose retrieval. This gives a total of 2 hours in saved operational time per operation.

A solution to solve this issue is to switch out the ordinary buoys with a buoyancy collar. The collar will be on the outside of the last 80 m of the Black Eagle hose. The right amount of buoyancy and placement of the collar will be a requirement for so that the creation of the lazy S will be an easy task for the ROV.

An example of a buoyancy collar used for pipes and hoses is shown in Figure 23, it is flexible and have low resistance towards waves.

Figure 23 Example of buoyancy collar on a hose (Pipefloats, 2013)

5. Calculations and Results

5.1 Calculations of pressure loss through the Black Eagle hose system

For the IMR vessels the standard procedure during pumping of chemicals for most wells is to set the pumping pressure to between 300 – 310 bars. As a safety measure a valve is installed on the topside that will bleed of the pressure when it is approaching 345 bar. The reason for this is that having a pump pressure topside that is too high can influence the reservoir pressure, and a too large pressure in the reservoir can cause it to fracture, rendering both reservoir and well useless.

In these calculations the theoretical pressure loss in a 2” Black Eagle hose will be investigated, this will be compared to the known pressure loss from performed operations and the theoretical accuracy will be discussed.

The theoretical pressure loss through a 3” Black Eagle hose will be calculated. Calculations towards finding a new maximum pump rate for the 3” Black Eagle hose will be performed.

These calculations will give grounds for assessments towards benefits of upgrading to a 3” Black Eagle hose.

5.1.1 Pressure loss through a 2” Black Eagle hose

It is known through previous scale operations that with the use of a 2” Black Eagle hose and a pump pressure of 310 bar will result in a flow rate of 1200 l/min.

The fluids traveling from the vessel will suffer a pressure loss through the length of the 2” Black Eagle hose and through the 2” subsea piping. A check valve called Moffat is installed in the piping close to the connection point for the Black Eagle hose. A static pressure of 50 bar is needed to keep this in an open position.

At the Xmas tree the fluids will move into the production tubing and travel down the well. Here the fluids will go into piping of sizes of normally 5” – 7”.

The pressure drop through the Black Eagle hose can be found by assistance from the manufacturers Black Eagle Product Manual. From Table 8 it can be shown by linear interpolation that a flow rate of 1200 l/min through a 2” (50 mm) Black Eagle hose will result in a pressure drop of 0.144 bar/m.

$$\frac{(1200-1000)*(0.21-0.1)}{(1500-1000)}+0.1=0.144\ bar/m$$

Table 8 Correlation between flow rate and pressure drop, from Black Eagle hose Product Manual (Parker Hannifin, 2010)

Flow rate	Pressure drop in bar/m	
l/min	ID of 2" (50 mm)	ID of 3" (76 mm)
700	0.05	0.01
1000	0.10	0.01
1500	0.21	0.03
2000	0.36	0.05
3000		0.11

Data related to the well:

- Vessel pump pressure 310 bar
- Moffat valve opening pressure 50 bar
- Pressure at Xmas tree 115 bar
- Black Eagle hose length 750 m
- Water depth 365 m
- Density of fluid 1023 kg/m^3
- Flow rate 1200 l/min

Real pressure drop from vessel to Xmas tree:

$310bar - 115bar = 195bar$

Calculation of theoretical pressure drop from vessel to Xmas tree:

Pressure loss due to length of Black Eagle hose:

$$750m * 0.144 \frac{bar}{m} = 108bar$$

Pressure loss due to fluid column:

$$365m * 1023 \frac{kg}{m^3} * 9.81 \frac{m}{s^2} * 10^{-5} = 36.6bar$$

Pressure loss due to the Moffat valve:

$$50bar$$

Pressure loss due to 10 m of subsea pipeline with 10 bends of 90°:

$$7.3bar$$

Total theoretical pressure loss:

$$108bar + 36.6bar + 50bar + 7.3bar = 201.9bar$$

This gives a theoretical pressure drop of 201.9 bar, and the pressure at the Xmas tree should be:

$$310bar - 201.9bar = 108.1bar$$

Difference in pressure loss, real versus theoretical:

$$195bar - 201.9bar = -6.9bar$$

This shows that the theoretical calculation is somewhat on the safe side, but a good representation of the pressure loss through this system.

The pressure loss due to fluids traveling through pipes and valves between the Black Eagle hose and the Xmas tree was calculated by a Fluid flow calculator (Pipe Flow Calculations, 2013), with the simplification that every 90° bend equals 0.9 m of straight pipe (The Engineering Toolbox, 2013).

5.1.2 Pressure loss through a 3" Black Eagle hose

By interpolation it can be shown that the correlation between the flow rate and the pressure drop in a 3" Black Eagle hose is as shown in Table 9.

Table 9 Correlation between Flowrate and pressure drop 3" Black Eagle hose

Flow rate	Pressure drop in bar/m
l/min	ID of 3" (76 mm)
1000	0.01
1100	0.014
1200	0.018
1300	0.022
1400	0.026
1500	0.03
1600	0.034
1700	0.038
1800	0.042
1900	0.046
2000	0.05

Data related to the well:

- Moffat valve opening pressure 50 bar
- Pressure at Xmas tree 115 bar
- Black Eagle hose length 750 m

Calculation of theoretical pressure loss from vessel to Xmas tree:

By increasing the flow rate in steps of 100 l/min and calculating the associated pressure loss we get the results as shown in Table 10. The pressure for the Moffat valve, fluid column, and the pipes with bends will be the same as in the calculations for the 2" Black Eagle hose.

Table 10 Calculations of theoretical pressure drop from vessel to Xmas tree

Flow rate l/min	Pressure loss due to length of Black Eagle hose	Total Theoretical Pressure loss
1200	$750 * 0.018 = 13.5$	$13.5 + 50 + 36.6 + 7.3 = 107.4$
1300	16.5	110.4
1400	19.5	113.4
1500	22.5	116.4
1600	25.5	119.4
1700	28.5	122.4
1800	31.5	125.4
1900	34.5	128.4
2000	37.5	131.4

For the next calculations the flow rate of 1800 l/min will be used, as for higher flow rates limitations will be given by the capacity of the vessel pumps or the permeability of the well.

Calculation of necessary vessel pump pressure (flow rate of 1800 l/min):

$$125.4bar + 115bar = 240.4bar$$

This gives a theoretical vessel pump pressure of 240.4 bar when pumping at a flow rate of 1800 l/min. It is therefore shown that it is possible to use a 3" Black Eagle hose for scale operations on these IMR vessels. An added bonus is that this pump pressure is lower than the usual pumping pressure using a 2" hose, reducing the work of the pumps.

5.1.3 Calculations of yearly pump hours saved from changing to a 3" Black Eagle hose

The data here is gathered from all previous scale operations performed for Statoil by Edda Fauna from the years 2010, 2011 and 2012. Only data from the successful scale inhibitor jobs are used for the calculations. The scale jobs not being considered are operations like scale dissolver operations or special case scale inhibitor operations where a higher flow rate would not be beneficiary.

For these calculations the flow rate of 1800 l/min will be used, as for higher flow rates limitations will be given by the capacity of the vessel pumps or the permeability of the well.

Calculations for 2010:

- Total scale jobs – 25
- Total successful scale inhibitor jobs – 20
- Average flow rate – 1056.5 l/min
- Total accumulated pump time – 219.03 hours / 9.13 days

Pump time in minutes:

$$219.03 * 60 = 13142\ min$$

Total liters pumped at flow rate of 1056.5 l/m:

$$13142 * 1056.5 = 13883976\ l$$

Time taken in minutes at a flow rate of 1800 l/m:

$$\frac{13883976}{1800} = 7713.3\ min$$

Time taken in hours at a flow rate of 1800 l/min

$$\frac{7713.3}{60} = 128.6\ hours$$

Days saved if all pumping had been performed at a flow rate of 1800 l/min:

$$\frac{219.03 - 128.6}{24} = 3.77\ days$$

The total time saved in 2010 if the pump rate had been 1800 l/m would be 3.77 days.

Calculations for 2011:

- Total scale jobs – 27
- Total successful scale inhibitor jobs – 18
- Average flow rate – 996.5 l/min
- Total accumulated pump time – 212.73 hours / 8.86 days

Pump time in minutes:

$$212.73 * 60 = 12764\ min$$

Total liters pumped at flow rate of 996.5 l/m:

$$12764 * 996.5 = 12718911\ l$$

Time taken in minutes at a flow rate of 1800 l/m:

$$\frac{12718911}{1800} = 7066.1\ min$$

Time taken in hours at a flow rate of 1800 l/min

$$\frac{7066.1}{60} = 117.8\ hours$$

Days saved if all pumping had been performed at a flow rate of 1800 l/min:

$$\frac{212.73 - 117.8}{24} = 3.96\ days$$

The total time saved in 2011 if the pump rate had been 1800 l/m would be 3.96 days.

Calculations for 2012:

- Total scale jobs – 22
- Total successful scale inhibitor jobs – 16
- Average flow rate – 1078.17 l/min
- Total accumulated pump time – 219.8 hours / 9.16 days

Pump time in minutes:

$$219.8 * 60 = 13188\, min$$

Total liters pumped at flow rate of 1078.17 l/m:

$$13188 * 1078.17 = 14218909\, l$$

Time taken in minutes at a flow rate of 1800 l/m:

$$\frac{14218909}{1800} = 7899.4\, min$$

Time taken in hours at a flow rate of 1800 l/min

$$\frac{7899.4}{60} = 131.7\, hours$$

Days saved if all pumping had been performed at a flow rate of 1800 l/min:

$$\frac{219.8 - 131.7}{24} = 3.67\, days$$

The total time saved in 2012 if the pump rate had been 1800 l/m would be 3.67 days.

Main results from the calculations of possible time reductions on previous scale operations, if the operations were performed with a 3" Black Eagle hose is shown in Table 11.

Table 11 Main results of yearly pump hour calculations

Year	Original pump time (days)	Calculated potential of time saved (days)	New pump time (days)	Percentage saved (%)
2010	9.13	3.77	5.36	41,3
2011	8.86	3.96	4.9	44,7
2012	9.16	3.67	5.49	40,1

These calculated results demonstrate the possibilities in reduced pumping days from previous operations. For coming years there is an expected increase in both scale operations and volumes to be pumped. This provides reason to assume that future potential of time consumption during scale pumping operations will increase as well.

These results can easily be turned into monetary values by looking at the day rates for these IMR vessels. Using a day rate of 1 million NOK for the IMR vessels the money saved per year will be in the range of 3.5 million to 4 million NOK. This gives an indication of how much could be saved from having a 3" instead of 2" Black Eagle hose.

5.2 Winch system

Scantech were not able to provide information or indicative prices for the reel and winch system necessary for the improved Black Eagle hose system described in 4.2. Prices and dimensions of the required system needs to be investigated further.

5.3 Black Eagle hoses

Indicative prices for the Black Eagle hose are:

- 2" Black Eagle hose → 7 000 NOK per meter of hose
- 3" Black Eagle hose → 21 000 NOK per meter of hose
- Rental price 2" Black Eagle hose → 50 000 NOK per day

The price for a 2" Black Eagle hose of 750 m:

$$750 * 7\,000 = 5\,200\,000\,NOK$$

The price for a 3" Black Eagle hose of 750 m:

$$750 * 21\,000 = 15\,750\,000\,NOK$$

Yearly rental price for a 2" Black Eagle hose, using 90 days for scale operations:

$$90 * 50\,000 = 4\,500\,000\,NOK$$

5.4 Buoyancy collar system

Parker has no previous experience with a system like this but believes that it can be produced.

The benefits of having a permanent buoyancy collar is that the launch and recovery time for the Black Eagle hose will be greatly decreased.

The time spent on deployment and recovery of the Black Eagle hose is around 3 hours per operation, with the new permanent buoyancy collar on the Black Eagle hose is assumed to save 2 hours.

The average of scale operations for the last 3 years:

$$\frac{25 + 27 + 22}{3} = 24{,}7\,operations$$

Calculation of possible time saved per year:

$$\frac{24{,}7 * 2}{24} = 2{,}1\ days$$

These results turned into monetary values by using a day rate of 1 million NOK for the IMR vessels gives money saved per year around 2.1 million NOK.

A permanent collar attached to the first 80 m of the Black Eagle hose will result in a higher outer diameter for this part of the hose, this can result in a need to have a bigger reel. An increased size might also cause problems related to the spooling device on the reel, extra space can lead to misplacement of the hose during reeling.

6. Discussion

This chapter will look into the challenging areas of scale operations and the improvement ideas developed and described in this thesis. Conclusions will be based on the results achieved and the educated assumptions implemented in this thesis.

6.1 Upgrade of flow Capacity (2” vs 3” Black Eagle hose)

As can be shown in the calculations in chapter 5.1.2 the system onboard the IMR vessels can handle a 3” Black Eagle hose. It will even lower the current pressure used for scale pumping. In theory the equipment will be able to pump chemicals at a flow rate of 1800 l/min with a pump pressure of 240.4 bar.

From the historical data collected during scale operations performed from 2010 to 2012 much useful information was extracted and used to indicate the potential for pump time reduction.

The results as given in Table 11 is as follows:

- The total pumping time for scale fluids during 2010 operations was 9.13 days, calculations for potential reduction if a 3” hose was utilized results in a reduction of 3.77 days or 41.3 %
- The total pumping time for scale fluids during 2011 operations was 8.86 days, calculations for potential reduction if a 3” hose was utilized results in a reduction of 3.96 days or 44.7 %
- The total pumping time for scale fluids during 2012 operations was 9.16 days, calculations for potential reduction if a 3” hose was utilized results in a reduction of 3.67 days or 40.1 %

These results demonstrate the potential in reduced pumping days from previous operations upgrading to a 3” Black Eagle hose with larger flow rate during the pumping.

These results turned into monetary values by using a day rate of 1 million NOK for the IMR vessels. The results gives money saved per year in the range of 3.5 million to 4 million NOK. This gives an indication of how much could be saved from having a 3” instead of 2” Black Eagle hose.

The future need for scale management is expected to increase in the coming years. For 2013 there is an increase in number of planned scale operations. Several wells operated by Statoil need regular treatments and the required chemical volumes are increasing compared to previous treatments.

The results for previous years and predictions for future scale management gives indications that an upgrade to a 3” Black Eagle hose will result in more than 40 % reduction in pumping time during scale operations and thereby reduce costs by 4 million NOK.

Looking at these factors there is reason to believe that for the coming years the equivalent results will lead to increases in time savings and also extra cost reductions for operations.

All the benefits of upgrading to a 3” Black Eagle hose needs to be compared to the disadvantages.

The most important disadvantages of upgrading to a 3” Black Eagle hose include:

- Higher hose price
- Higher hose weight
- Requires more space
- Bigger reel and winch system
- Higher reel and winch price
- Need to upgrade current assist equipment (buoys, chute, etc.)

Looking into the extra costs of upgrading the 2” hose to a 3” hose, some comparisons can be made by looking at the Black Eagle hose prices.

A 3” hose costs 15.75 million NOK and this is equal to a difference of 10.55 million NOK compared to a 2” hose. The extra capacity of the 3” hose saves around 4 million NOK per year from reduced time of scale operations. The yearly savings of 4 million NOK will within three years lead to the extra costs of acquiring a 3” hose to be earned back.

The 3” Black Eagle hose costs are not the only extra cost that needs to be considered when upgrading the hose diameter. There will be extra costs towards the reel and winch system, the buoyancy system as well as other various equipment.

Assuming that the costs of the Black Eagle hose system upgrade to a 3” hose isn’t extremely high and the expected rise in future scale operations, the upgrade of flow capacity by utilizing a 3” hose is considered a profitable solution compared to the current 2” hose and flow capacity.

It will be desirable to investigate these costs further so that an accurate point in time where a 3” hose is a more profitable solution than a 2” hose can be found.

6.2 Owning versus renting of Black Eagle hose system

Considering a 2” Black Eagle hose the procurement cost is 5.2 million NOK, this is very close to the yearly rental price of 4.5 million NOK. If only considering hose prices, owning the 2” hose will become more profitable than renting well within two years. However there will also be costs towards a reel and winch system and towards installation and maintenance of the hose system. These extra expenses needs to be investigated further to find a more exact intersection point where the solution of owning is considered profitable compared to renting. By educated assumptions, the extra expenses are believed to be below or around 10 million NOK. The intersection point for profitability will be within 4 years. This gives a strong indication that owning is cheaper than renting for a 2” Black Eagle hose system.

6.3 Improved permanently installed Black Eagle hose system

The costs of the new Black Eagle hose system consisting of, reel and winch with constant tension and heave compensation systems are assumed to be high. But then again this system can lead to the benefit of increasing the operational weather window from 4 m Hs to 5 m Hs. The ability to perform scale operations in rougher weather can lead to less time spent Waiting on Weather (WoW) and more time used to perform operations. All days used for WoW is very expensive when the vessel day rates are at 1 million NOK/day. The weather is very uncertain and it is therefore very varied if scale operations are affected by bad weather. Vessel WoW can vary from days to weeks over the timespan of a year. In cases where the weather is between 4-5 m Hs the new system can provide the opportunity to improve scale treatment operations. The new system will also reduce forces on the hose which can lead to longer lifetime of the Black Eagle hose.

The new Black Eagle hose system with the desired support systems is dependent on the placement onboard the vessel to be able to function properly. The new placement will be on the upper deck as indicated in Figure 21. The new placement will free up much space on work deck, as the Black Eagle hose will now go directly from upper deck down into the moonpool. There might be some modifications needed on the vessel for installation of the new Black Eagle hose system on the required position.

For this proposed Black Eagle hose system there is many benefits to be gained and several costs that needs to be accounted for. The benefits need to be measured up against the costs of procuring, installing and maintaining this system.

Upgrade benefits likely to produce savings:

- No daily rental price
- No need for Waiting on Weather between 4-5 m Hs
- Reduced mobilization time
- Active heave compensation and constant tension
- Reduced loads on the Black Eagle hose
- Improved Black Eagle hose lifespan
- More free space on work deck
- The Black Eagle hose winch can be controlled both from operations room and manually on the reel
- Possibilities to reduce personnel needed on deck

The costs for new Black Eagle hose system include:

- Cost of Black Eagle hose
- Cost of reel and winch system
- Cost of constant tension and heave compensation systems
- Cost of installation on vessel
- Maintenance costs

The pros of this system are extremely beneficial and are believed to greatly prevail over the costs in the long run. Future operations is expected to become much smoother, better and cheaper.

6.4 Permanently installed buoyancy system

The calculations in chapter 5.4 show that it is possible to save around 2.1 days or 2.1 million NOK per year from reducing the combined deployment and recovery time by 2 hours.

Since the use of a permanently installed buoyancy system is unknown in connection with Black Eagle hoses, there will be need to further explore this possibility. A system that can function both on the reel and subsea, to create a lazy S configuration for the Black Eagle hose needs to be designed.

Factors which needs to be addressed to check feasibility:

- The cost of the new system versus the money saved by it
- The space use of the old buoyancy system versus the new system
- No longer have the need for personnel to manually attach buoys
- What influence will the new system have on the reel and winch system
- Find the intersection point where the new system is the profitable solution

The proposed system with buoyancy collar modules installed on the hose will lead to a need for extra space on the reel, this can lead to big challenges for the reel and spooling apparatus. The possible challenges of the buoyancy collar system should be investigated to check if this solution can be considered feasible.

The prices of the buoyancy collar are not expected to be extremely high, so the biggest challenge is towards the space use on the reel.

7. Conclusion

The following conclusions can be drawn with background in the results and discussions presented in this thesis.

The current standard for scale operations is to rent a Black Eagle hose system at expensive day rates for the required periods of scale operations. Indicative prices and calculations show that a 2" Black Eagle hose costs 5.2 million NOK to buy and the rental price is 4.5 million NOK. The extra expenses for reel and winch system, installation and maintenance are believed to be below or around 10 million NOK. These numbers lead to an intersection point for profitability of ownership of hose system within 4 years. Based on the prices, calculations and assumptions presented in this thesis the solution of owning the Black Eagle hose system is cheaper in the long run compared to renting it.

Calculations show that the systems onboard the IMR vessels can handle the upgrade to a 3" Black Eagle hose, it will even lower the necessary pump pressure for scale pumping. The theory gives a pump pressure of 240.4 bar and a flow rate of 1800 l/min for chemical pumping.

Calculations of previous scale operations and expected increase for scale management and scale operations in the years to come gives indications that pumping time and costs can be reduced. Calculations show that it can be expected to reduce pumping time by more than 40 % and that costs will be reduced from around 4 million NOK and upward by upgrading to a 3" hose instead of a 2" hose.

If only considering hose prices, the results gives the costs of a 3" hose to be 15.75 million NOK and the price difference is 10.55 million NOK compared to a 2" hose. The yearly savings of 4 million NOK will within three years lead to the extra costs of acquiring a 3" hose to be earned back. Having to consider extra costs towards the reel and winch system, the buoyancy system as well as other various equipment. If the costs of these support systems become too large it will lead to the option of having the 3" Black Eagle hose system become a non-profitable solution.

Assuming that the costs of the Black Eagle hose system upgrade into a 3" hose isn't extremely high and the expected rise in future scale operations, the upgrade of flow capacity by utilizing a 3" hose is considered a profitable solution compared to the current 2" hose and flow capacity.

It can be concluded that a new placement of the Black Eagle hose system at the upper deck can lead to, possibilities to use support systems that previously was impossible to use. These new support systems will help reduce loads on the Black Eagle hose and lead to an increased operational weather window for scale operations. The benefits of this new system and its placement need to be measured up against the costs of procuring, installing and maintaining this system.

The pros of this system are extremely beneficial and they are believed to greatly prevail over the costs in the long run. Future operations will be smoother, better and cheaper.

Given that the buoyancy collar doesn't create big issues with the reel and the spooling apparatus, it is considered to be a good solution that quickly will benefit future scale operations.

8. Future work

The work performed in this thesis is intended to be used as a basis for further discussions regarding improvements to the Black Eagle hose systems on Statoil IMR vessels.

The expenses for the Black Eagle hose, winch system and maintenance should be investigated further to confirm that the intersection point is fairly accurate for where the solution of owning is considered profitable compared to renting.

It will be desirable to investigate the costs of upgrading to a 3” Black Eagle hose system further so that an accurate intersection where a 3” hose is a more profitable solution than a 2” hose can be found.

For future work regarding the improved permanently installed Black Eagle hose system, the costs of this system should be investigated further. Data regarding previous WoW between 4-5 m Hs for scale operations should be calculated, where probable days and money saved if operations could have been carried out. System costs and probable savings should then be compared, also the other possible benefits should be evaluated to give a thorough basis towards the feasibility and greatness of the proposed system.

The option of replacing the current buoyancy system with a permanent buoyancy collar will have to be investigated further. Cost of changing buoyancy system to collars and other system modifications compared with expected savings.

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