DrillWell

DRILLING AND WELL CENTRE FOR IMPROVED RECOVERY

Annual Report 2014

DrillWell – Drilling and Well Centre for Improved Recovery

sfi Centre for Research-based Innovation

Established by the Research Council of Norway

IRIS

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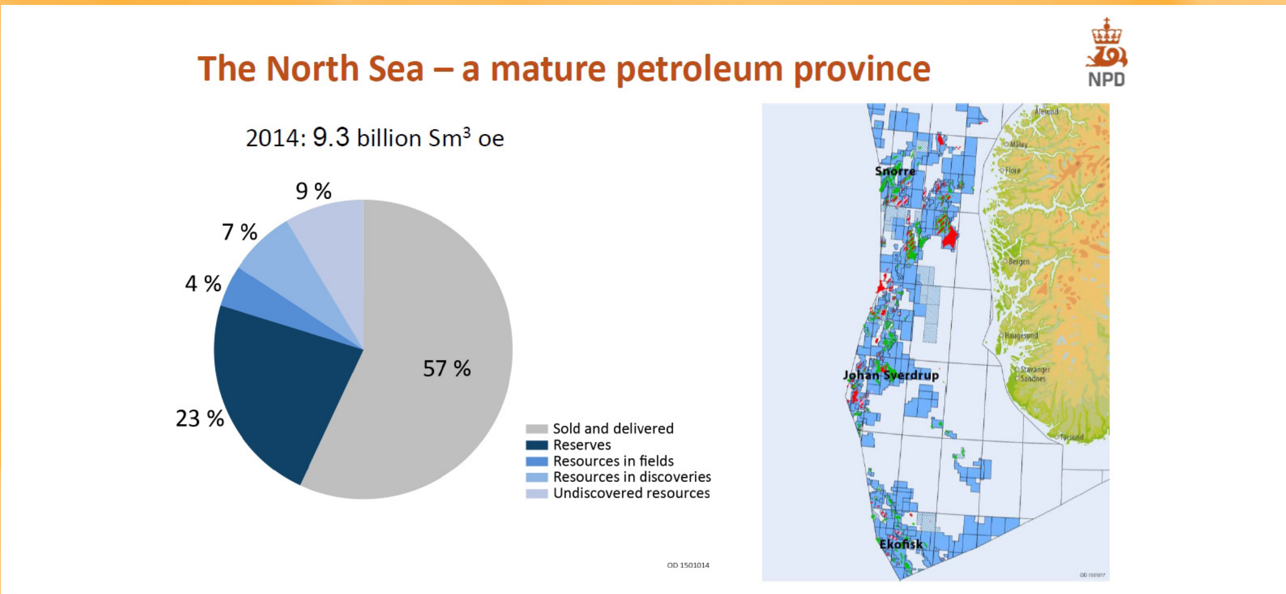
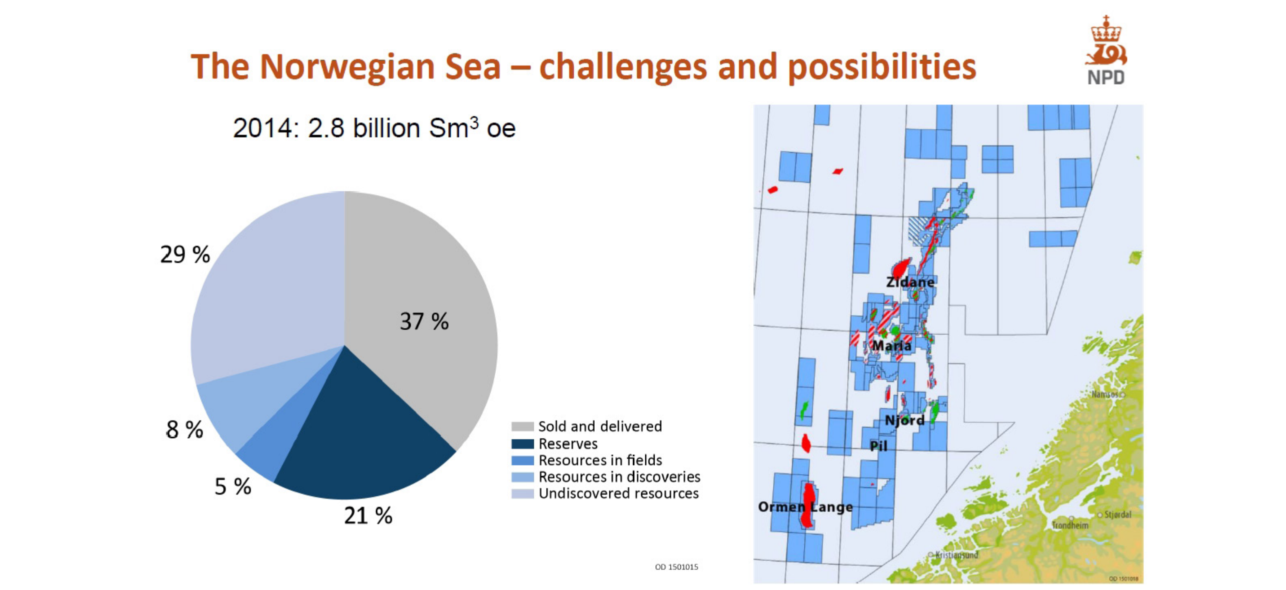
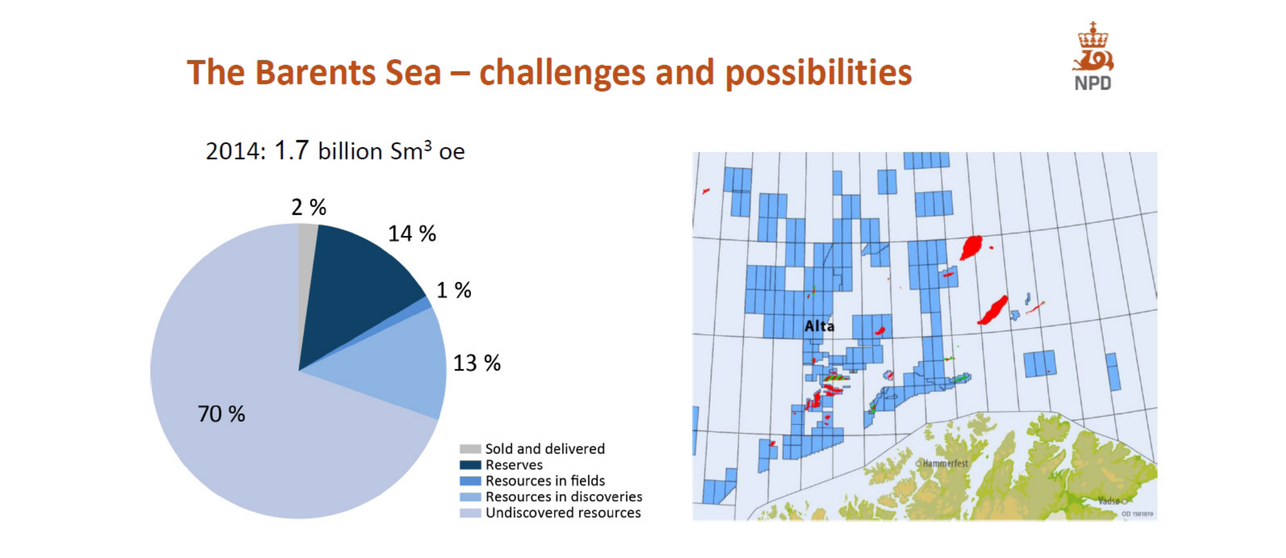
NTNU – Trondheim
Norwegian University of Science and Technology


The North Sea – a mature petroleum province
NPD
2014: 9.3 billion Sm³ oe
9 %
7 %
4 %
23 %
57 %
Sold and delivered
Reserves
Resources in fields
Resources in discoveries
Undiscovered resources
Snorre
Johan Sverdrup
Ekofisk


The Norwegian Sea – challenges and possibilities
NPD
2014: 2.8 billion Sm³ oe
29 %
37 %
8 %
5 %
21 %
Sold and delivered
Reserves
Resources in fields
Resources in discoveries
Undiscovered resources
Zidane
Maria
Njord
Pil
Ormen Lange


The Barents Sea – challenges and possibilities
NPD
2014: 1.7 billion Sm³ oe
2 %
14 %
1 %
13 %
70 %
Sold and delivered
Reserves
Resources in fields
Resources in discoveries
Undiscovered resources
Alta

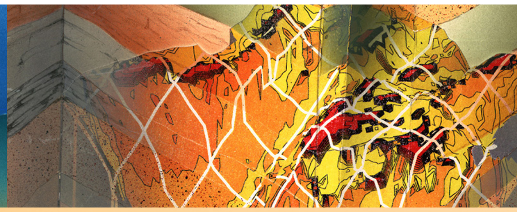
Introduction

The Drilling and Well Centre for Improved Recovery (DrillWell) is an industry-driven collaboration and innovation environment with industrial partners funding, prioritizing and directing R&D efforts towards their requirements and challenges. Six industry partners are funding the Centre with a total of NOK 30 million annually.

The Centre is also funded with additional NOK 10 million annually by the Research Council of Norway (RCN) as a Centre for Research-based Innovation (SFI), implying a 5- to 8-year time framework.

The Centre was fully established and became operational in June 2011.





Content

Vision

Unlock petroleum resources through better drilling and well technology.

Objective

The Centre's objective is to improve drilling and well technology providing improved safety for people and the environment and value creation through better resource development, improved efficiency in operations and reduced cost.

Cost reduction

Innovative drilling and well technology is needed to reduce exploration and development costs, as well as well plugging and abandonment.

Improved recovery

Improved wells at lower cost will imply higher recovery of oil and gas by increasing the number of wells and their productivity.

Efficient field development

Improved wells at lower cost will imply cost-efficient field development. Today the wells represent 50-60% of the field development cost.

Technology gaps

The Centre is focusing on a number of technology gaps:

- Formation and well integrity prediction, monitoring and control
- Monitoring and control of well temperature, pressure and multiphase flow in complex wells
- Real-time drilling and well data utilization
- Integration of subsurface and surface drilling and well data
- Imaging ahead of and around the wellbore during drilling
- Updating the earth model while drilling
- Intra-field well monitoring for optimized field drainage and well integrity
- Low cost well intervention
- Cost-efficient and safe plugging and abandonment of wells (P&A)

Way to the market

The realization of R&D results is to be through spin-off projects which will ensure that the developed technology and solutions will be commercially available in the market. These projects will be developed outside the Centre`s activities, and aim at a targeted development and qualification process in cooperation with the service industry and smaller companies (SMEs) in order to produce commercially available products/services.

Applications

The Centre is increasing its focus on the application of technology and methods that have been developed in close cooperation with our industrial partners:

- Software for drilling optimization and managed pressure drilling, assisting operational decision support
- Methods for deep imaging and geosteering, assisting optimal well placement and improving safety and drilling efficiency
- Laboratories for cement evaluation, assuring optimal cement selection and as a first step towards monitoring and predicting well integrity

Service providers and vendors will be invited to join the Centre on a project basis and in spin-off projects.

Low cost field development

Technology development and applications will be especially important with a low oil price. There is a need to develop new technologies both for low cost field development and for field life extension.

Industry partners perspectives

Halvor Kjørholt Statoil, Chairman of DrillWell Board:

Drilling and well represent approximately 50% of the investment on the Norwegian Continental Shelf. The cost has increased by 15% annually the past 10 years up to 2014. Despite this, no particular increase in efficiency has been registered in the period and the non-productive time has not been reduced. The offshore drilling industry is thus facing a major efficiency challenge. An element that adds to this general picture is the growing number of P&A and slot recovery operations. Today there is an urgent need to find the key to increased efficiency and reduced cost in well construction and P&A operations. DrillWell has a role to play in this picture by generating and following up new ideas. We believe academic-based research is one of the keys as it questions old truths and brings ground-breaking expertise and new ways of thinking to the industry.

Rune Woie ConocoPhillips, Member of DrillWell Board:

ConocoPhillips has a long history on the NCS and is focused on how to continue operations in the future. During these years R&D activities have been important to the company in order to improve and develop new technology and methods for increased production, recovery and improved efficiency and cost competitiveness.

ConocoPhillips has close focus on a number of different R&D projects within the thematic areas in the DrillWell Centre. The DrillWell project is aligned with and gives a good supplement to our R&D project portfolio. In the coming years there will be an increased focus in the Centre to implement results so that the partners in the Centre can realize value or reduce risks and improve predictability of operations through the funds put into the R&D programme.

Arild Saasen Det norske oljeselskap, Member of DrillWell Board:

The DrillWell programme has contributed positively towards minimizing the drilling cost of conventional wells and by increasing the probability of reaching drilling targets. Within technology for Plug and Abandonment (P&A) of wells in particular, the DrillWell project has presented significant potential improvements. The research programme and results have been communicated to the authorities and oil service industry. As a result, the project has been one of the elements contributing to the recent reduction in the cost of P&A operations.

Torgeir Larsen Wintershall, Member of DrillWell Board:

The DrillWell centre is the main initiative in the Wintershall D&W research project portfolio. During the short timeframe in which the centre has been operating, Wintershall has transformed from an exploration company to a company performing developments, production and also the challenges associated with tail production at the Brage field. Our scope of work is wide.
DrillWell continued work to identify ways to improve performance and efficiency, investigating methods to reduce risks and lower operational cost will be valuable contributions to Wintershall operations.
Realisation of results must be emphasised in the years to come. The real value of the centre will be proven first when research results are implemented in methods, products and services. We hope the continued efforts from DrillWell and industry partners will «Make this happen».

DrillWell as part of a National Technology Strategy

Technology development will be critical for safety, cost reduction and improved resource/production development

Challenges for the future of offshore petroleum activities

New technology has a significant potential to improve drilling performance and reduce non-productive time. The most important contribution for recovery from old and new fields is to reduce the drilling and well costs significantly. Reduced drilling costs will result in more wells drilled and higher recovery from producing fields.

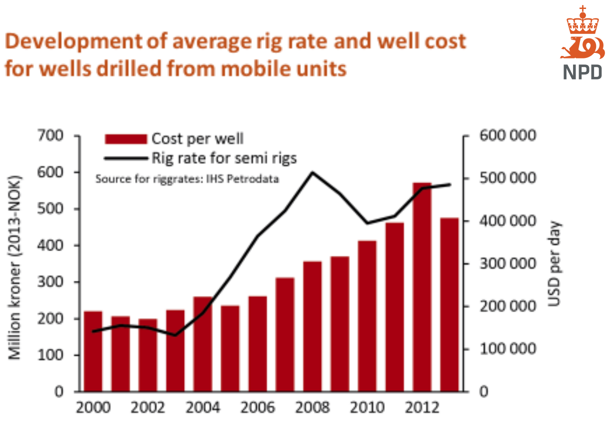


Figure A.

Drilling and wells costs on the Norwegian Continental Shelf amount to about NOK 100 billion annually which is about 50% of the total investment cost. The drilling and wells cost per well for production wells have doubled in the last 10 years according to the Norwegian Petroleum Directorate (NPD) illustradet in figure A:

Each year the industry drills fewer platform wells with a higher cost than before. With the present performance and solutions we will therefore not be able to extract the remaining resources within the lifetime of the installations.

Total petroleum resources in discovered and future fields

The Norwegian Petroleum Directorate (NPD) estimates the total petroleum resources on the NCS to be 14.1 billion Sm3 o.e. oil and gas (about 90 billion bbl o.e.) illustrated in figure B. During the 43 years from 1971 to 2013, 45 % (6.4 billion Sm3) has been produced. Still 7,7 billion Sm3 o.e. (about 50 billion bbl o.e.) of O&G resources remains to be produced in the future from resources in fields, discoveries and undiscovered resources (45% of oil and 55% of gas). Of these 7.7 billion Sm3 o.e. resources, 4.9 billion Sm3 o.e. is in discovered fields while 2.8 billion Sm3 o.e. is in fields to be found. **Technological development is crucial to extract the remaining petroleum resources.**

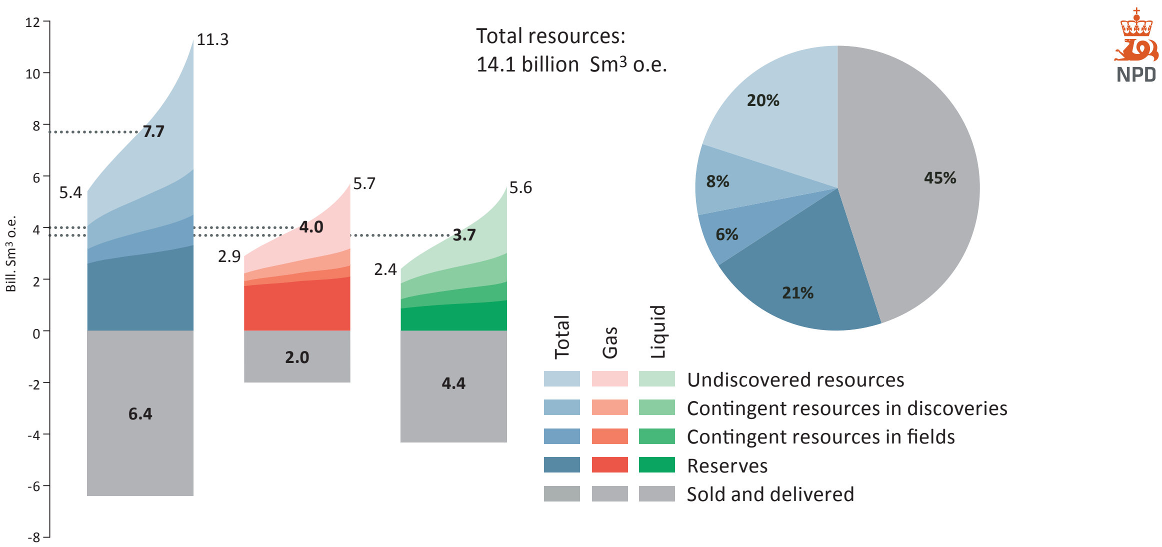


Figure B.

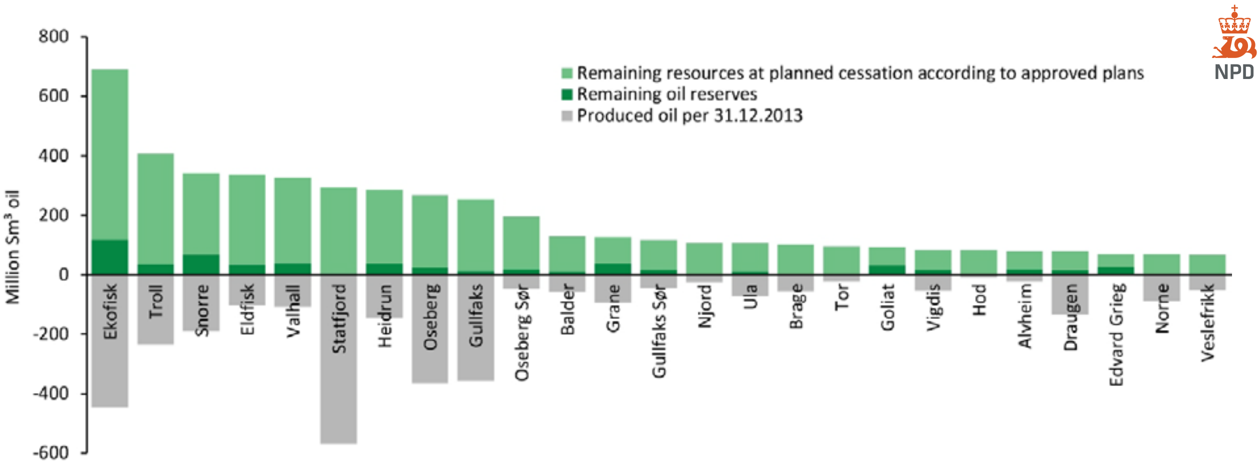


Figure C.

Remaining oil in place resources in discovered fields

The second important resource base are the resources that are "not decided to produce" of the total oil in place. These resources come in addition to the NPD numbers in figure B. We are talking about the oil in place in the major "old" oil fields: Ekofisk, Troll, Snorre, Eldfisk, Valhall, Statfjord, Heidrun, Oseberg, Gullfaks and 16 additional smaller fields. NPD reports these numbers in light green in figure C:

NPD estimates the remaining oil in place after planned production in these 25 fields to be about 4200 million Sm3. About 10% of these resources are already included in the numbers for "contingency resources in fields" in the previous figure Fig. B. But still there is a significant amount that is not yet decided to exploit. This is an ultimate target for drilling and well technologies together with EOR/IOR technologies. A possible goal might be to capture 25% - 35% (1000–1500 million Sm3) of these additional resources "not decided to produce" with game changing technologies. We are thus talking about significant resources in well-established producing fields and with installations in place ready to be used. This may require development that is critical in terms of timing.

Policy implication

To extract the remaining resources we need to increase the number of wells significantly by more efficient drilling solutions and lower costs. The drilling costs will have to be reduced in order to be in a position to drill enough wells for these resources.

Drilling and well technology for reduced costs, increased productivity and improved resource development

The need to reduce specific drilling and well costs significantly

80% of total well cost is proportional to time and 20% is equipment related. The difference between "best performance" and "avarage performance" is mainly related to handling operational problems. "Best performance" represents a 50% time reduction related to "average performance". We have operational challenges related to formation, surface equipment and drill string. Focus on these elements will improve problem avoidance and consequently provide improved safety and significantly reduced costs.

Loss of well integrity has been a challenge and has resulted in significant operational costs and loss of production. Focus on life cycle integrity, including formation stability, is consequently an important area. This affects all cycles from drilling and production to P&A.

The total accumulated number of wells (including branches, sidetracks and reentries) on the NCS is about 5560 of which 4030 have been production wells and 1530 exploration wells. About 2100 are presently operating and 270 wells are temporarily plugged. An additional ~1600 wells are reported as "plugged", but where the degree of plugging may range from a set of mechanical plugs to finished well plugging except final cutting of the wellhead. These P&A operations may take anything from a few days to the same time as it took to drill the well in the first place and will to some extent need access to the full drilling capacity on the platform/availability of a mobile rig. We thus have a significant number of wells that will need to be plugged and abandoned (P&A) on the NCS in the future.

Cost reduction focus:

- Improve **operational performance** (by avoiding problems) - potential reduction of total time with 40%-50%
- Improve **well design** and design elements that provide **simpler operations** (both time and equipment) during total life cycle of the well
- Improve **well design** and design elements that provide simpler operations for **P&A wells**

Resource/production improvements:

- **Reduced time** (costs) will provide the opportunity to **drill more wells** providing increased resources and production capacity
- Improved **drilling technology and intelligent drilling** (including look ahead/look around) will improve the drilling precision of reservoir penetration and enhance resource development
- Improved **well design** will **enhance productivity** and **increase production** capacity also by reduced water production

DrillWell and the National Technology Strategy – future solutions

DrillWell R&D priorities are in full compliance with the OG21 National Technology Strategy for the Petroleum Industry in drilling and wells. OG21 underlines that the annual costs of drilling and wells can be reduced by about NOK 20 billion in the next few years given focused technology development. DrillWell`s priority is to contribute to the OG21 strategy **for cost reductions and improved efficiency**.

A key to future solutions to improve drilling efficiency and reduce drilling costs is to **combine technologies** and to get synergies between the drillers, reservoir engineers and geoscientists. In order to produce **"game changing" technologies** we need a **collaborative environment** with oil companies, service companies, R&D institutes and universities. Further we need to cooperate internationally with the best technology environments in industry and academicy groups. DrillWell has this as its strategy.

DrillWell Innovation Strategy – Next step

R&D to the market in collaboration with the service industry

The four scientific partners have a solid platform in oil- and gas- related R&D. This has formed a basis for DrillWell which, together with the industry partners and the Research Council of Norway (NFR), have invested NOK 140 million in the past 3.5 years. This has resulted in a significant R&D portfolio and knowledge basis for continued technology development.

The DrillWell collaborative environment focuses on solutions for:

- Improved **operational performance** by avoiding problems - potential reduction of total time by 40%-50%. Reduced time and costs provides the opportunity to drill more wells giving increased resources and production capacity
- Improved **drilling technology and intelligent drilling** including look ahead/look around that will improve the **drilling performance and precision** of reservoir penetration and enhance resource development
- Improved **well design** that provides simpler operations (both time and equipment) during **total life cycle** of the well including **P&A**
- Improved **well design** that will **enhance productivity** and **increase production** capacity also by reduced water production

The solutions for these challenges are critical to improve drilling efficiency and resource development on the Norwegian Continental Shelf. Avoiding problems and improved operational efficiency will also improve safety.

To realize these solutions a close collaborative environment between R&D, oil companies and service industry is important.

These challenges are also common in most offshore provinces internationally.

Service company cooperation and focus

There is a strong tradition among the R&D partners for cooperation with service companies. Such cooperation will now be in focus for the future activities of DrillWell.

A primary ambition is to realize the availability of these technologies in the market. In this connection **key areas/ projects** will be selected together with the oil company partners. DrillWell is now in the process of selecting these projects and presenting them to service companies for further development and commercialization.

The figure below illustrates this process:

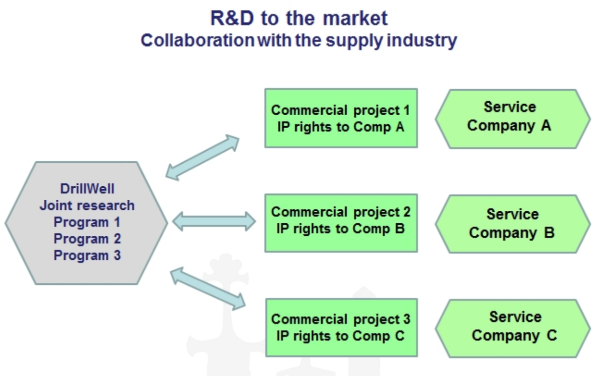


Figure D.

The realization of these projects is expected to be joint activities between the DrillWell partners and the service companies. The intention is to provide IP rights connected to these products to the selected service companies. These activities will require separate financing.

DrillWell Collaborative Environment

There is a strong interaction between the scientists at the Research Partners and the supervisors and specialists at the Industry Partners. The oil companies are directing the work through the Board, the Technical Committee and specialists monitoring and guiding each research area.

DrillWell partners

Research partners

SINTEF IRIS UiS NTNU – Trondheim Norwegian University of Science and Technology

Industry partners

Statoil ConocoPhillips TOTAL DETNORSKE TALISMAN ENERGY wintershall

International academic partners

THE UNIVERSITY OF TEXAS AT AUSTIN UNIVERSITY of HOUSTON UC San Diego TU Delft Delft University of Technology

We have on-going scientific cooperation with the following universities in Programmes 1 and 2:

- University of Texas at Austin within Deep Imaging and Geosteering
- University of Houston within Managed Pressure Drilling
- University of California at San Diego within Managed Pressure Drilling
- Delft University of Technology within Deep Imaging

Additional academic network

The Centre's scientists and PhD students also have an extensive network within the international research community at other prominent universities including:

- Texas A&M University
- University of Southern California at Los Angeles
- University of Tulsa
- University of Calgary
- MINES ParisTech
- University of Clausthal
- University Simon Bolivar (Venezuela)
- Curtin University (Perth)
- Chulalongkorn University (Bangkok)

Programmes and projects

Drilling and Well Centre for Improved Recovery

PROGRAMME 1
Safe and Efficient Drilling Operations for Cost Reduction
- ROP Management and Improvement
- Formation Integrity
- Managed Pressure Drilling
- Determining Changes in Oil-based Mud during Well Control Situations

PROGRAMME 2
Drilling Solutions for Improved Recovery
- Geosteering and Deep Imaging
- Flexible Earth Model

PROGRAMME 3
Well Solutions for Improved Recovery
- Well Integrity
- Plugging and Abandonment
- Water Shut-Off

The following sections present a summary of the ongoing activities.

IRIS OFFICE

UIS CAMPUS

NTNU CAMPUS

SINTEF PETROLEUM OFFICE

PROGRAMME 1

Safe and Efficient Drilling Operations for Cost Reduction

Programme 1 addresses technologies and methods to avoid drilling-related problems and improve safety and drilling performance. In 2014, four projects have addressed key challenges within:

- ROP Management and Improvement
- Formation Integrity
- Managed Pressure Drilling
- Determining Changes in Oil-based Mud during Well Control Situations

The project objectives span from fundamental research through to the development of industrial prototypes. The diversity of these projects reflects the broad expertise found among the research partners.

Drilling Process Management and Improvement encompasses most of these aspects and is the key cost and safety factor in all drilling operations.

Some highlights from 2014 are given below.

ROP Management and Improvement

Motivation

When drilling a well the rate of penetration (ROP) is mainly affected by (1) bit properties, (2) weight exerted on the bit, (3) rotational speed of the bit, (4) formation properties, and (5) pressure difference between well and formation.

In DrillWell, this project has previously focused on optimization of ROP with respect to cuttings transport. In 2014, the objectives have been to improve the estimation of downhole mechanical friction and correction of hook load measurements. These are both essential contributions to be able to estimate accurate weight and torque on bit, and also evaluate the condition of the wellbore.

Project description and results

One sub-task in the *ROP Management and Improvement project* has focused on correction of hook load measurements. Accurate measurement of the weight of the drill string is important in order to estimate the correct weight on bit, and thereby detect drilling problems. However, the hook load measurement usually obtained from the drilling control system is not the lifting force acting on the drill string, but is extracted from the tension in the dead line or measured from a sensor at the top drive. Both ways of measuring hook load are inaccurate and can result in a difference of several tonnes compared to the true lift force.

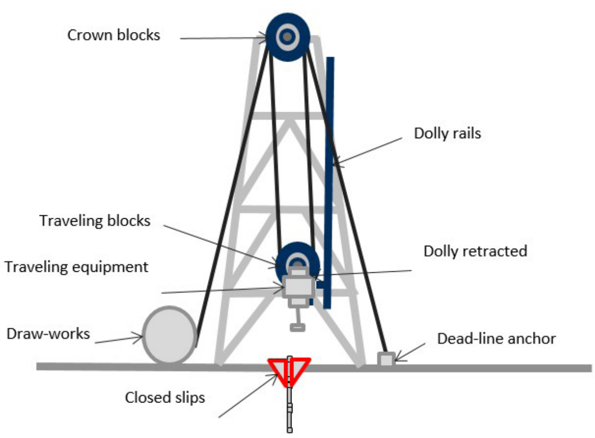


Figure 1: Schematic showing that the dolly can be retracted while making a connection.

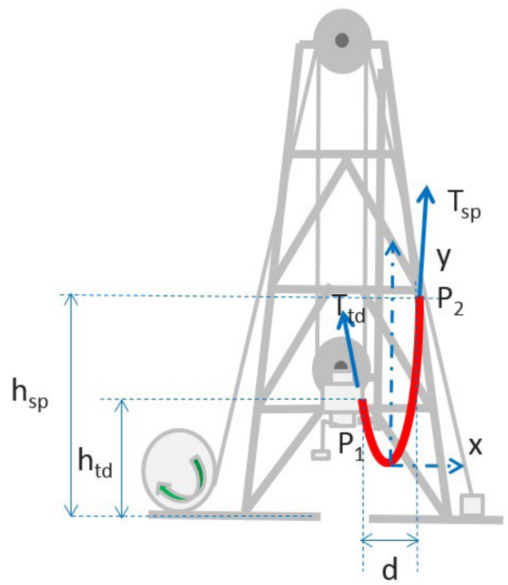


Figure 2: Schematic view of the effect of the mud hose and top drive umbilical on the travelling equipment.

During 2014 a model for correction of hook load has been developed which takes into account the effects that have an impact on the measured hook load, and computes a corrected value as a better estimate of the true lift force. Assessment of model uncertainty and its effect on hook load predictions is given particular attention as this ultimately determines whether the correction method can replace direct hook load measurements in practice.

Conclusions

Validation against field data where sensors both at the top drive and at the dead-line anchor have been used, proves that the model is very accurate. The hook load correction model works exclusively at the software level and represents a potentially cost-efficient alternative to a direct hook load sensor installed in the internal BOP of some top drives.

References

E. Cayeux, T. Mesagan, S. Tanripada, M. Zidan and K.K. Fjelde, "Real-Time Evaluation of Hole Cleaning Conditions Using a Transient Cuttings Transport Model", SPE Drilling and Completion Journal, Vol. 29, No. 1, 2014.

E. Cayeux, B. Daireaux, E.W. Dvergsnes, H. Siahaan, and J.E. Gravdal, "Principles and Sensitivity Analysis of Automatic Calibration of MPD Methods Based on Dual-Gradient Drilling Solutions", presented at the SPE Deepwater Drilling and Completions Conference held in Galveston, Texas, USA, September 10-11, 2014.

E. Cayeux, H.J. Skadsem and R. Kluge, "Accuracy and Correction of Hook Load Measurements During Drilling Operations", submitted for presentation at the SPE/ADC Drilling conference and exhibition, London, March 17-19, 2015.

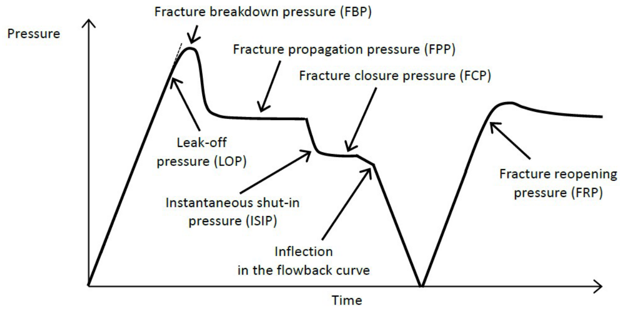


Figure 3: Schematic view of bottom hole pressure vs time in an extended leak-off test (XLOT). The initial test and one repeat cycle are shown.

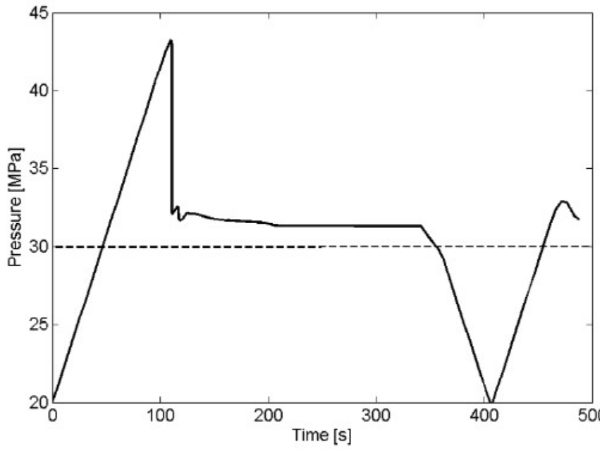


Figure 4: Simulated borehole pressure vs time.

Formation Integrity

Motivation

Extended leak-off test (XLOT) is one of the few techniques available for stress measurements in oil and gas wells. Interpretation of the test is often difficult since the results depend on a multitude of factors, including the presence of natural or drilling-induced fractures in the near-well area.

Project description and results

In this project, coupled numerical modelling of XLOT has been performed in order to investigate the pressure behaviour during the flow-back stage as well as the effect of a pre-existing fracture on the test results in a low-permeability formation. Essential features of XLOT known from field measurements have been captured by the model, including the saw-tooth shape of the pressure vs injected volume curve, and the inflection in the pressure vs time curve during flowback used by operators as an indicator of the bottom hole pressure reaching the minimum in-situ stress.

Conclusions

The Formation Integrity project has taken simulation of fracture propagation during extended leak-off tests to a new level and developed an advanced model, which may improve the estimation of the fracture pressure gradient. Reduced uncertainty concerning formation integrity and the response of the formation to fracturing will improve both the operational progress and the reliability in well integrity monitoring/prognosis.

References

A. Lavrov, I. Larsen and A. Bauer, "Numerical modeling of extended leak-off test with a pre-existing fracture", paper submitted to Journal of Rock Mechanics and Geotechnical Engineering (Jan. 2015).

Managed Pressure Drilling

Motivation

For drilling narrow pressure margin wells or in depleted reservoirs, Managed Pressure Drilling (MPD) is seen as a valuable method. However, the level of instrumentation and in particular access to downhole pressure data is a limiting factor to achieve accurate and robust pressure control. One key research topic has therefore been to investigate these limitations and also the possibilities when increasing the level of instrumentation, e.g. by wired drill pipe, or by using well flow models.

Project description and results

Possibilities and limitations by using back-pressure MPD has been an ongoing topic since 2013. Experiments using a high fidelity well flow model have resulted in several papers listed below. A new topic in 2014 has been alternative well control procedures, specially adapted to back-pressure MPD equipment and instrumentation level. A kick incident during MPD operations is typically handled by conventional well control methods, at least if the kick is estimated to be larger than a threshold value. In this project two alternative well control procedures specially adapted to backpressure MPD have been evaluated: the dynamic shut-in (DSI) procedure and the automatic kick control (AKC) procedure. Both methods capitalize on improvements in Pressure While Drilling (PWD) technology. A commercially available PWD tool buffers high-resolution pressure measurements which can be used in an automated well control procedure. By using backpressure MPD, the choke valve opening is tuned automatically using a feedback-feedforward control method.

The two procedures are evaluated using a high fidelity well flow model and cases from a North Sea drilling operation are simulated.

Conclusions

Significant improvements can be achieved in terms of accuracy and robustness of an MPD system if sensor placement, instrumentation level and data quality are addressed during the planning and execution of MPD operations.

Well control procedures during back-pressure MPD operations can be improved by utilizing the MPD choke and specially designed control algorithms. The benefit is reduced kick volume and reduced non-productive time because drilling can be resumed earlier compared to traditional well control procedures.

References

H. B. Siahaan, K.S. Bjørkevoll and J. E. Gravdal, "Possibilities of Using Wired Drill Pipe Telemetry During Managed Pressure Drilling in Extended Reach Wells", presented at the SPE Intelligent Energy Conference and Exhibition, Utrecht, April 1-3, 2014.

H. Siahaan, E.H. Vefring, J.E. Gravdal and M. Nikolaou, "Evaluation of Coordinated Control During Back Pressure MPD Operations", presented at the SPE Bergen One Day Seminar, April 2, 2014.

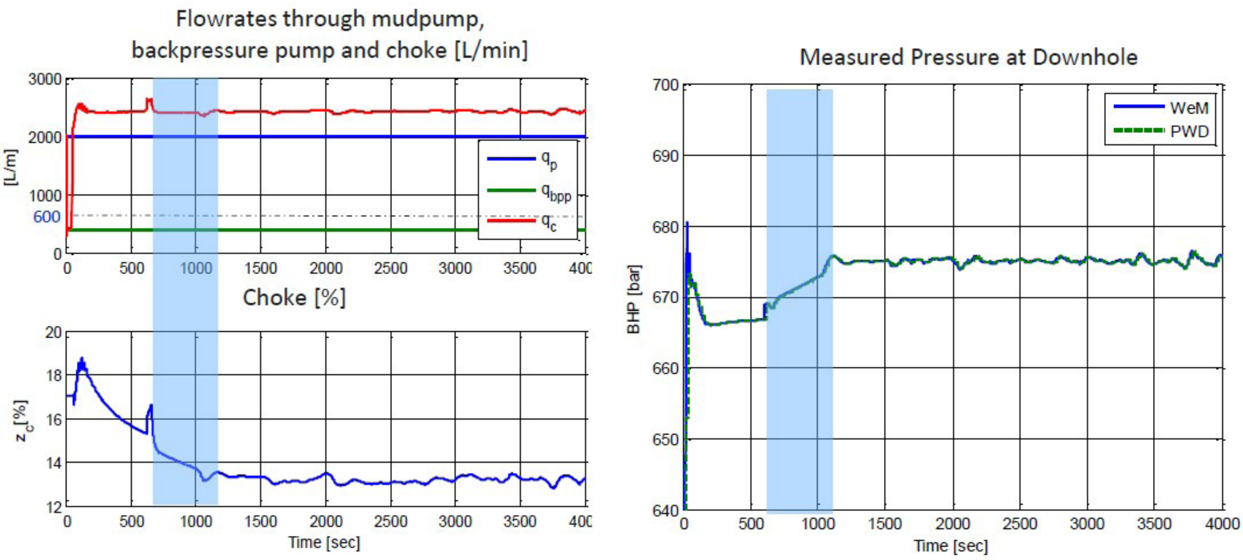


Figure 5: Flow rates, choke opening and bottom hole pressure during an alternative well control procedure (the AKC procedure) using PWD measurements. The blue band indicates the time from kick has been detected to a new pressure set-point has been estimated, and circulation of gas is initiated.

J.E. Gravdal, H. Siahaan and K.S. Bjørkevoll, "Back-Pressure Managed Pressure Drilling in Extended-Reach Wells – Limiting factors for the ability to achieve accurate pressure control", presented at the SPE Bergen One Day Seminar, April 2, 2014.

K.S. Bjørkevoll, B. Daireaux and P.C. Berg, "Possibilities, Limitations and Pitfalls in Using Real-Time Well Flow Models During Drilling Operations", paper prepared for presentation at the SPE one day seminar, Bergen, April 22, 2015.

J. Zhou, J.E. Gravdal, P. Strand and S. Hovland, "Automated Kick Control Procedure for an Influx in Managed Pressure Drilling Operations by Utilizing PWD" to be submitted to SPE Drilling & Completion Journal, 2015. The paper is based on work presented at the 2014 IADC Well Control Conference Europe December 2-3, 2014. See interview of J. Zhou on http://www.drillingcontractor.org/case-study-automatic-kick-control-reduces-kick-size-time-to-establish-control-of-well-31966.

J. Zhou and M. Krstic, "Adaptive Predictor Control for Stabilizing Pressure in a Managed Pressure Drilling System under Time-delay", Journal of Process Control (submitted), 2014.

Determining Changes in Oil-based Mud during Well Control Situations

Motivation

The understanding of kick and oil-based mud (OBM) interaction is essential for the planning and operational safety of drilling. Absorption of drilled volumes of reservoir fluids and gas leaking from a reservoir into the drilling mud will occur even in overbalance situations; more pronounced the higher the pressure. In order to characterize the gas loading into the OBM and the potential severity of gas release during depressurization, knowledge about the gas loading capability and impact on rheology as a function of OBM-type and process conditions is essential.

Project description and results

The first task for the project is the determination of the gas loading capability and impact from gas loading on rheology at HPHT-conditions; max 1000 bar and 200°C. Two different OBMs in terms of base oil are investigated; a «normal mineral» base-oil; EDC 99DW/ OBM: EMS-4600, and a «linear paraffin» base-oil; Sipdrill 2.0/ OBM: EMS-4400. The fluids were supplied by MI-Swaco. A key issue is to determine the difference in the OBMs characteristics with respect to gas loading and rheology at the HPHT-conditions. A specially designed HPHT-test unit has been established for this purpose in the initial part of the project.

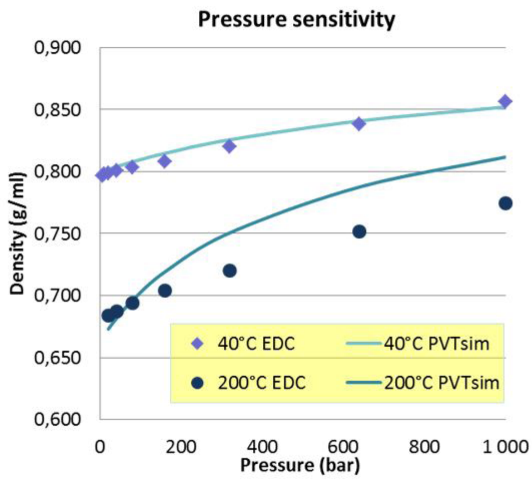
The project work in 2014 has comprised the establishment of operational procedures and methodology for the HPHT test unit, first covering the base oils and then the associated OBMs. For the latter special considerations are made to eliminate the impact of barite sag on density and rheology measurements. Test matrices have been completed for the two base oils EDC 99DW and Sipdrill 2.0. In addition to phase envelope determination of base oil-methane mixtures, the density sensitivity with respect to temperature and pressure for selected methane gas mass fractions has been determined and compared to prediction with the simulation software PVTsim.

The density sensitivity to pressure and temperature for the base oil EDC 99DW without methane exposure is shown in Figure 6. The results show that whereas PVTsim accurately predicts the density at lower pressure and temperatures, there is significant overprediction of density results as the HPHT-region is approached. In 2015, the HPHT-investigation will continue with two selected OBMs.

The second task of the project concerns the determination of the gas rate at which base oils (BO) absorb the reservoir gas. A specially designed test unit resembling gas bubble exposure to liquid in a vertical annuli will be utilized for determining the gas absorption rate, gas swelling of the liquid, and effective viscosity and density as a function of the gas loading of the liquid concerned. As for task 1 a key issue is the comparison of gas absorption characteristics between the two types of base oil; «normal mineral-» and «linear paraffin-» types. The first test results are scheduled for Q1 2015, after the performance tests are completed with a well model fluid.

Conclusions

The experimental results give valuable insight in gas loading capabilities and rheology of OBMs at HPHT conditions, in particular revealing differences between two OBMs widely in use, one made of a «normal mineral» base-oil; EDC 99DW (OBM: EMS-4600), the other made of a «linear paraffin» base-oil; Sipdrill 2.0 (OBM: EMS-4400). The results for the base oils indicate that the density is significantly overestimated with the standard simulation software PVTsim as the HPHT-region is approached.



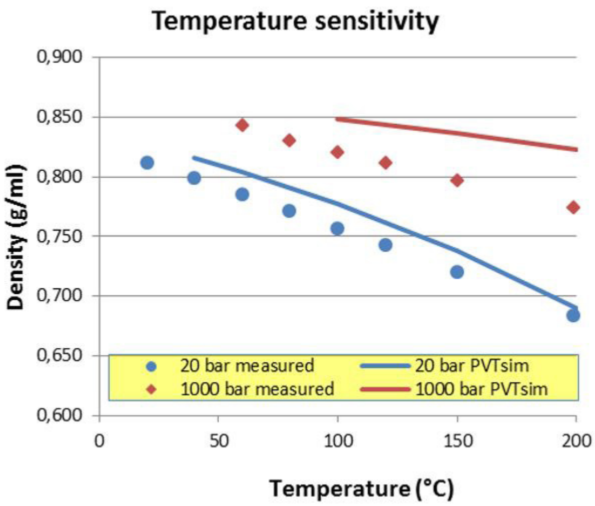


Figure 6: Measured density sensitivity (symbols) for the base oil EDC 99DW vs. pressure (left) and temperature (right) as compared to predictions with PVTsim.

PROGRAMME 2

Drilling Solutions for Improved Recovery

In 2014, Programme 2 addressed two projects with key challenges within:

- Geosteering and Deep Imaging
- Flexible Earth Model

Geosteering and Deep Imaging

Motivation

High resolution deep imaging and geosteering have the potential to greatly improve oil recovery by being able to optimize the well placement in the reservoir. Real-time high resolution deep imaging will also improve drilling safety and efficiency by enabling problem avoidance.

Project description and results

The objective is to develop methods and algorithms for deep imaging (imaging ahead and around the wellbore) and geosteering in order to improve well placement and geometry, support the decision-making process while drilling, and make an optimum use of data acquired during drilling.

In 2014, geosteering studies continued to employ the previously established framework that involves theories in ensemble-based uncertainty estimation, decision-making and ensemble optimization. Equipped with these multidisciplinary analytic tools, our main efforts have been dedicated to studying proactive geosteering operations in more realistic, yet more complex settings. Specifically, a practical issue has been considered, in terms of the potential presence of errors/biases in geomodels.

Model errors may be present in a geomodel due to, for example, our limited knowledge of the geological structure (e.g., faults) and the restriction of the practical geomodel resolution. Our investigation (see Figure 7) suggests that taking into account the potential presence of model errors would improve the accuracy of the ensemble Kalman filter (Chen et al., 2014).

The presence of faults will lead to discontinuities in a geomodel, and this can be considered as one of the sources of model errors. In the presence of faults, if one applies the ensemble Kalman filter (EnKF) to model reservoir boundaries, poor results may be obtained (see Figure 8b)). To account for this, a special procedure is designed to detect the potential presence of faults. Our investigation shows how incorporating the fault-detection procedure into the estimation process results in a better

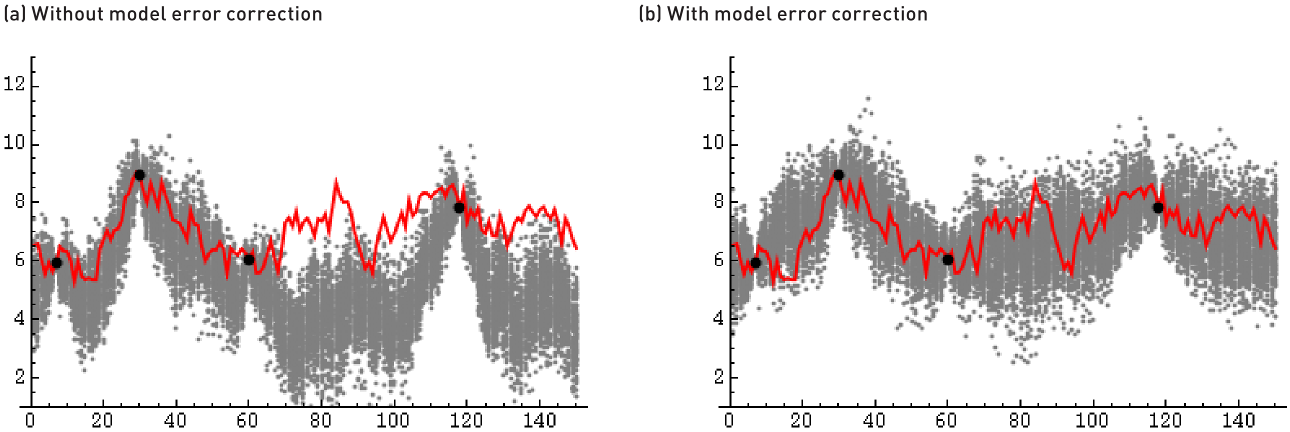


Figure 7: The estimated model parameters with and without model error correction. The red curve is the true model. The black dots show the location of the data. The grey dots show an ensemble of models.

(a) Gridblock error parameter (b) No model error estimation (c) With model error estimation

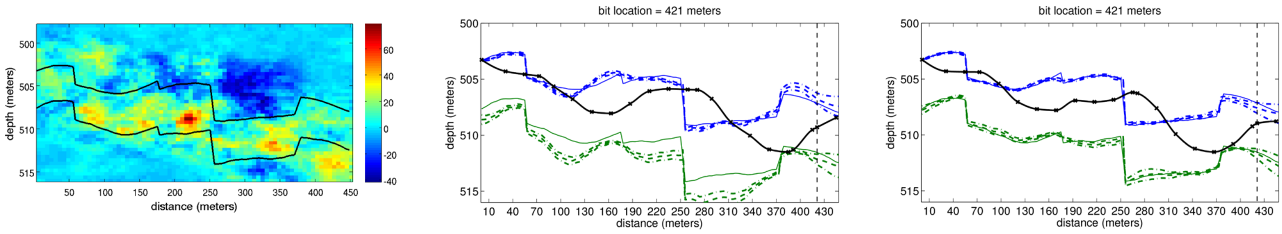


Figure 8: (a) Estimated grid block model error parameters with true reservoir boundary overlaid. Estimated reservoir boundaries without (b) and with (c) fault detection. In (b) and (c), the solid lines represent the true model, the dashed lines are the mean estimate, the dash-dotted lines show the uncertainty in the estimate (plus and minus one standard deviation), blue curves represent the top surface, green curves represent the bottom surface, the black solid curve represents the well path, and the vertical dashed line indicates the drill bit location.

match with the subsurface and hence better geosteering decisions (see Figure 8).

In addition, a decision analytics process supporting decision making while drilling has been developed. Promising results have been published in a multi-objective geosteering case study (Kullawan et al., 2014).

A synthetic study, using both simple and more realistic reservoir models, has also been performed to evaluate the added value of using advanced electromagnetic modelling in the context of model updating while drilling. The effects of faulting and drilling fluid invasion have been studied for various transmitter/antenna combinations (example in Figure 9).

(a) Reservoir model (b) Modelled amplitude of the electric field at f=100 kHz (c) Modelled amplitude of the electric field at f=2 MHz

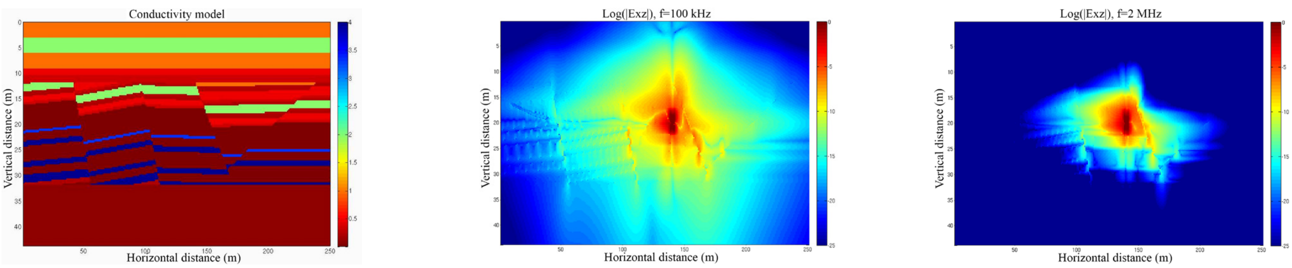


Figure 9: Example of the modelled amplitude of the electric field in a reservoir model (a) with a transmitter frequency of (b) 100 KHz, and (c) 2 MHz. The borehole is invaded by oil-rich drilling mud.

For seismic deep imaging, a new methodology for deep local imaging using redatumed borehole seismic data by interferometry has been developed. Numerical studies confirmed the potential of such a data-driven approach. In addition, the possibility of turning the drill-bit noise into virtual receivers using seismic interferometry has been investigated (Liu et al., 2014a;, 2014b).

Conclusions

The development of a consistent methodology for model updating during drilling combining the EnKF approach with the use of advanced modelling tools has significant potential for improving recovery through better geosteering decisions. With the new hardware developments coming from the industry, it will also ensure an optimum use of the data acquired while drilling and thereby improve drilling safety and efficiency by enabling problem avoidance.

Flexible Earth Model

Motivation

The increased amount of measurements available in real time while drilling with wired pipe opens new possibilities for the optimization of well placement. The continuous stream of new information reduces uncertainty and allows revisions of the geological interpretations made prior to the drilling operation. This requires effective interpretation, integration and utilization of the new information within the timeframe set by the on-going drilling operation. Current three-dimensional earth modelling tools have limited capabilities for local alterations. Model modifications are complex and labour intensive, and the time needed for updating the model exceeds the time available during drilling operations.

Our aim is improved support for decision-making processes while drilling, by real-time integration of the most current and precise information obtained during the drilling operation. Our objective is to always obtain an up-to-date earth model.

Results

The complexity when managing existing earth models is largely a result of their application of a single and globally defined grid for storing physical properties. This grid must be completely re-constructed in a time-consuming process for example when inserting a new sedimentary layer into the model. Furthermore, management of the geological structure with its faults and horizons requires considerable manual work. Starting from scratch, we have developed several methods to address these challenges. First, the structure and petrophysical properties are separately managed, enabling local updates of the structure while re-using the existing properties. Second, a multi-scale strategy allows management of the earth model independent of scale. This enables high resolution in the part of the subsurface that is of interest to the current application, e.g. around the well being drilled, and lowers resolution away from the region of interest. We also develop methods for automatic control of the structure, based on geological rules and parameters. The new framework will enable effective management of the subsurface uncertainties around the well while drilling.

Integration with the other software prototypes being developed in the programme is prioritized. The aim is to demonstrate how the combination of new methods enables improved decision support and optimal placement of the well, based on the most recent downhole observations.

Conclusions

The present project focus is on validation and demonstration of the fundamental principles of the recent developments, and on exploring new functionalities that capitalize on the advantages offered by the new approach.

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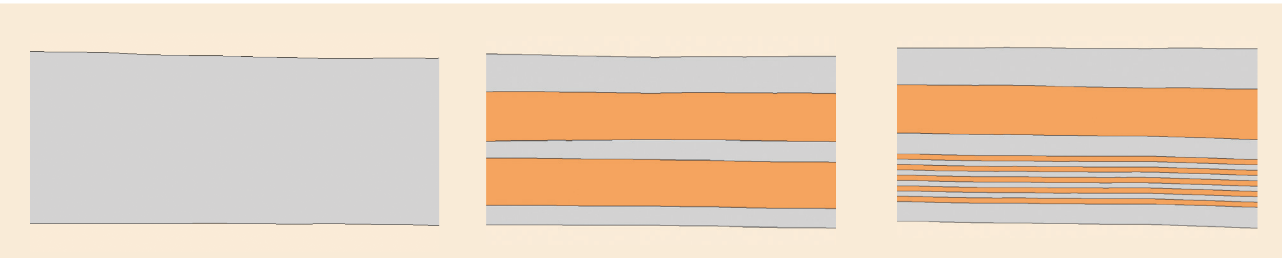

Figure 10: Multi-scale stratigraphy as a step on the way towards multi-scale earth modelling. The model resolution is higher around the reservoir in the lower part of the model to the right.

PROGRAMME 3

Well Solutions for Improved Recovery

Wells are an invariable prerequisite for the recovery of hydrocarbons. Any technical progress that makes it technically and financially possible to drill more wells and ensure effective, reliable, long-lasting functionality of existing wells is therefore a valuable contribution to improved oil recovery.

In 2014, Programme 3 addressed three projects with key challenges within:

- Life-Cycle Well Integrity
- Plug and Abandonment
- Water Shut-Off

Life-Cycle Well Integrity

Motivation

During production, failure of well barriers may lead to leakages from the well. As a consequence, the well may be shut-in or abandoned, thereby causing significant production loss. Maintaining well integrity throughout the life-cycle of the well is therefore important in order to improve recovery.

Project description and results

The best way to ensure well integrity during production is to include emphasis on well integrity already in the well planning phase. By implementing such an initial life-cycle well integrity approach, several problems and costs can be avoided during production and also after well abandonment. In this project, the emphasis has been put on well barriers – to understand why well barriers fail, and also on well design – to understand how initial well design influences long-term well integrity.

Influence of thermal cycling on cement sheath integrity

One of the most important well barrier elements is the annular cement sheath. Well temperatures cycle up and down as a part of normal production operations, and this thermal cycling in the well can have a detrimental effect on the integrity of the cement sheath.

A tailor-made laboratory set-up has been built to study the effect of thermal cycling on the integrity of different annular sealants such as cement (Albawi et al., 2014; De Andrade et al., 2014). With this unique experimental set-up, it is possible to study cement integrity for complete casing-cement-rock samples at downhole conditions, and the performance of different cement systems can be evaluated. The formation of micro-annuli and cracks in the cement sheath is monitored and visualized by X-ray Computed Tomography (CT).

Major findings so far have been that the cement sheath integrity during thermal cycling is dependent upon initial well conditions, such as casing centralization, type of casing surface, presence of mud, and type of rock (De Andrade et al., 2014; De Andrade et al., 2015).

Cement-formation bonding

A typical failure mode of the cement sheath is the formation of microannuli, which can be formed both during primary cementing and during production. Drilling fluids present in the wellbore will influence microannuli formation and cement bonding.

Several laboratory experiments have been performed in order to further understand cement-formation interactions and cement-formation bonding in particular (Opedal et al., 2014). Different rock samples have been cemented with and without drilling fluids present and the quality of the cement-formation bonding has been characterized by X-ray Computed Tomography.

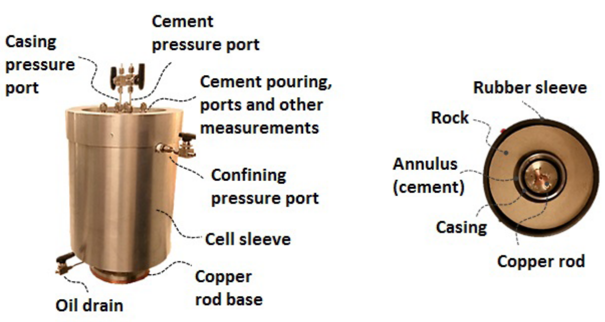

Figure 11: Side view (left) and top view (right) of custom-built pressure cell in experimental set-up for determination of cement integrity during thermal cycling (De Andrade et al., SPE-173871).

Conclusions

A good understanding of well barrier failure modes and the influence of well design on long-term well integrity is important in order to ensure well integrity throughout the life-cycle of the well.

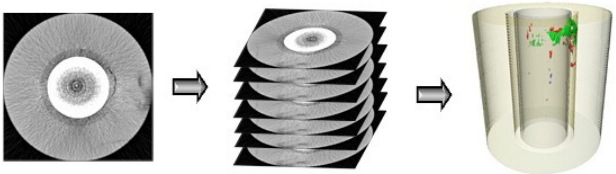

Figure 12: Process for visualization of cement integrity by analyses of X-ray Computed Tomography (CT) images. (De Andrade et al., SPE-173871).

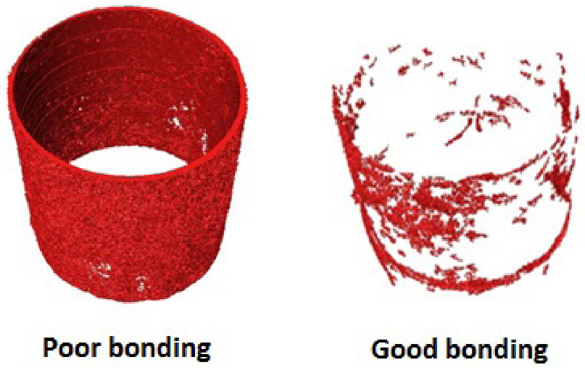

Figure 13: Visualization of mud films at different cement-formation interfaces by analyses of X-ray Computed Tomography images.

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J. De Andrade, S. Sangesland, J. Todorovic and T. Vrålstad, "Cement Sheath Integrity During Thermal Cycling: A Novel Approach for Experimental Tests of Cement Systems", paper prepared for presentation at the SPE one day seminar, Bergen, April 22, 2015.

N. Opedal, J. Todorovic, M. Torsæter, T. Vrålstad and W. Mushtaq, "Experimental Study on the Cement-Formation Bonding", presented at the SPE International Symposium on Formation Damage Control, Lafayette, Louisiana, USA, February 26-28, 2014.

Plug and Abandonment

Motivation

Thousands of wells need to be plugged and abandoned on the NCS in the next few decades, and this will be both time-consuming and very costly. As most plug and abandonment (P&A) operations currently require a drilling rig, it is important to find less time-consuming and more cost-effective methods, since these drilling rigs instead should be used to drill new wells and thereby improve recovery.

Project description and results

There are several important problem areas within P&A. For this project, two main topics have so far been selected; permanent plugging materials and P&A of subsea wells.

Portland cement is currently used as plugging material in most P&A operations. There are however some situations where cement is not so well suited, and there is a need for availability and qualification of alternative plugging materials for use in P&A operations.

P&A of subsea wells usually require semi-submersible rigs, which have high day rates. Since P&A operations can be very time consuming, it can be costly to plug and abandon subsea wells. Also, these semi-submersible rigs should preferably be used to drill new wells. It is therefore important to find ways to make P&A operations less time-consuming and more cost-effective, and to move parts of or all of the operation to Light Well Intervention Vessels.

Long-term integrity of plugging materials

One of the most important requirements of permanent plugging materials is long-term integrity at downhole conditions. Ageing tests have been performed where four different plugging materials were exposed to different downhole chemicals at elevated temperatures and pressures. Two different cement systems, one polymer-based material and one geopolymer were tested to determine their long-term integrity.

The results show that all the materials are affected by most of the chemical environments, but in different ways.

Geopolymers as potential plugging materials

Geopolymers are a type of inorganic, rock-like materials that can be seen as «artificial rock», and can be based upon different raw materials such as fly ash, kaolinite and various rocks. The rock-like nature of geopolymers make these materials potentially suited as permanent plugging materials. Work is currently ongoing where different types of geopolymers are prepared and evaluated as potential plugging materials (Khalifeh et al., 2014).

Tubing left in hole

Significant time during P&A operations is spent on removing steel tubing from the well. If the tubing could be left in the well instead of removed, considerable time and cost could be saved – especially for subsea wells since a rig is required for tubing removal. By leaving the tubing in hole, the P&A operation can be simplified and potentially be performed rig-less (Moeinikia et al., 2015).

Full-scale tests have been performed where the objective was to determine if it is possible to obtain a good cement seal when tubing is left in hole. 7" tubings were cemented with expandable cement in 9 5/8" casings with and without control lines. Focus was on determining the effect of control lines on the sealing ability of the cement.

Cost and time estimation of subsea multi-well P&A campaigns

Given the large number of wells to be abandoned in the near future, there is a need for structuring the cost and time estimation for large field P&A campaigns. Wells can be categorized based upon well type and abandonment complexity, and the P&A operations can be planned and performed in multi-well campaigns in order to optimize time use and improve cost efficiency.

A probabilistic approach has been developed to forecast distribution curves for the duration of P&A operations, in order to be able to plan for use of Light Well Intervention Vessels. Unexpected events, learning effects, and dependency between sub-operations inside a single well and between wells have been included into the model. The output is statistical values of estimated time and cost that can be used for budgetary planning and to improve decision making during planning of subsea multi-well P&A campaigns (Moeinikia et al.. 2014: Moeinikia et al., 2015).

Conclusions

Considerable time and costs can be saved during P&A operations with increased focus on research and development of new methods and technologies.

Figure 14: Full- scale tests to determine if a good seal can be obtained after P&A when tubing is left in hole: Stretching control lines at tubings during preparations (left) and cut sample with control lines cemented in place (right).

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Figure 15: Full-scale assembly for «tubing left in hole» tests.

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Water Shut-Off

Motivation

Injected fluids (water, chemicals, gas, etc.) should be efficiently utilized to displace formation oil (and increase oil recovery), whereas produced fluid composition should be optimized with respect to quantity and quality of the unwanted (water and/or free-gas) fluids. In addition, produced formation fluids will require separation and possibly reinjection (either one or both water and gas) for various reasons, such as formation pressure maintenance, lack of or reduced disposal capabilities, or lack of pipeline for gas transportation to the market.

Project description and results

This study is aimed at using environmentally friendly, water-soluble silicate systems for water management and shut-off applications in the field to address water production challenges.

Feasibility of Using Water-Soluble Silicates as DPR Systems

A laboratory-based screening and evaluation of a sodium silicate system was carried out for managing water production in carbonate naturally fractured reservoirs. In this screening process the gelant's viscosity, pH, and filterability; gelation time and kinetics of the gelation process; strength of formed gel against applied external forces, gel stability, gel shrinkage, and post-gelation time behaviour were investigated. The addition of certain polymer additives was also studied to evaluate potential improvements on formed gel properties. Several bulk and coreflood tests were conducted and based on a combination of all observed results the following can be stated:

- Two methods were used to measure the gel time and monitor the gelation process; the tube test and the dynamic oscillatory test.
- The addition of synthetic polymers and/or biopolymers to the main sodium silicate solution reduces the gelation time, which is further reduced when crosslinker is added in the case of the synthetic polymer. The addition of either a synthetic polymer or a biopolymer can significantly improve the viscosity of the gellant system. The biopolymer additive to the base sodium silicate solution is a promising viscosification agent for the type of sodium silicate considered in this study without significantly sacrificing the formed gel final strength. Gelant systems containing biopolymer resulted in a more shear thinning behaviour than other systems.
- Besides the relatively higher viscosity, a combination of base sodium silicate and biopolymer exhibited a lower filterability through certain filter sizes compared to the base sodium silicate gelant; the combination of these two effects can enhance the controllability of placement of the treatment system in a fractured medium.
- Gelant systems containing synthetic polymers, with or without crosslinker, gel faster and yield significantly weaker gels based on the Maximum Compression Pressure (MCP) strength tests.
- Gradual increase of a formed gel temperature during maturation process may result to improved gel strength.
- At a fixed aging temperature, MCP increases with time and tends to level off gradually after a certain time. After a fixed aging time, MCP increases with increased aging temperature, with this trend levelling off at a system-dependent temperature.
- Although some shrinkage was observed in practically all core scale experiments, the resulting permeability in post-gelation floods was significantly lower than the original fracture permeability especially in the most promising examined gelants.

Feasibility of Using Water-Soluble Silicates as DPR Systems

Whereas the use of silicate systems for either near or deep reservoir placement has been effectively demonstrated, its use as a Disproportional Permeability Reduction (DPR) in production wells appears to be more challenging. Based on several laboratory coreflood results obtained so far:

- The injection of sufficiently large volumes of sodium silicate chemical yields a lower residual oil saturation in the treated zone and reduced water cut at a given oil saturation of the treated zone.
- A DPR system placement at low water cuts affects both the effective permeabilities of oil and water – an indication that bullhead well treatments should be avoided.
- On the other hand, DPR placement at high water saturations (water-cuts) may increase the risk of total blockage of the treated reservoir zone.
- Effective permeability vs. oil saturation curves may shift to lower residual oil saturations; this may be an indication of formation wettability effects due to the alkaline nature of some of the silicate systems used.

Conclusions

Proper understanding of the water source and reservoir characteristics are of paramount importance for effectively *addressing water production problems. The use of environmentally friendly silicates for total zone (near-well and deep-formation) isolation is very promising; on the other hand, the application of water-soluble silicates as DPR agents is more complicated, with the underlining mechanisms being currently under investigation to enable their proper screening and potential for field application.*

References

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Academy

The Centre organizes projects for MSc and PhD students to work on our industry-defined topics within the three research programmes.

PhD students and post-doctoral fellows are employed by the University of Stavanger and NTNU.

Seven PhD students are engaged, three of these are female. During 2014, nineteen MSc students were involved in the research projects.

Papers from scientists and PhD students have been presented at high level conferences in Houston, Galveston, Forth Worth, Lafayette (Louisiana), San Francisco, Denver, Amsterdam, Utrecht, Sicily, Beijing and Bergen.

The Centre will also plan for structured competence development in collaboration with and for the oil companies. The first course available is "Life cycle well integrity".

Visit of the students from NTNU Department of Petroleum Enginering and Applied Geophysics.

Conference and Journal Papers

During 2014 a total of 17 papers were presented at international conferences in Houston, Galveston, Forth Worth, Lafayette (Louisiana), San Francisco, Denver, Amsterdam, Utrecht, Sicily, Beijing and Bergen. Nine papers have been published in international journals.

Governance

The Board is comprised of representatives from the Industry Partners as well as the Research Partners. The Chair of the Board is elected from industry and industry governance is secured through voting rules giving one vote to each industry member and one joint vote to the research partners. The Research Council of Norway is present on the Board as an observer.

The Technical Committee (TC) is an advisory body for both the Board and the Centre Manager, and has a coordinating responsibility across programmes and projects.

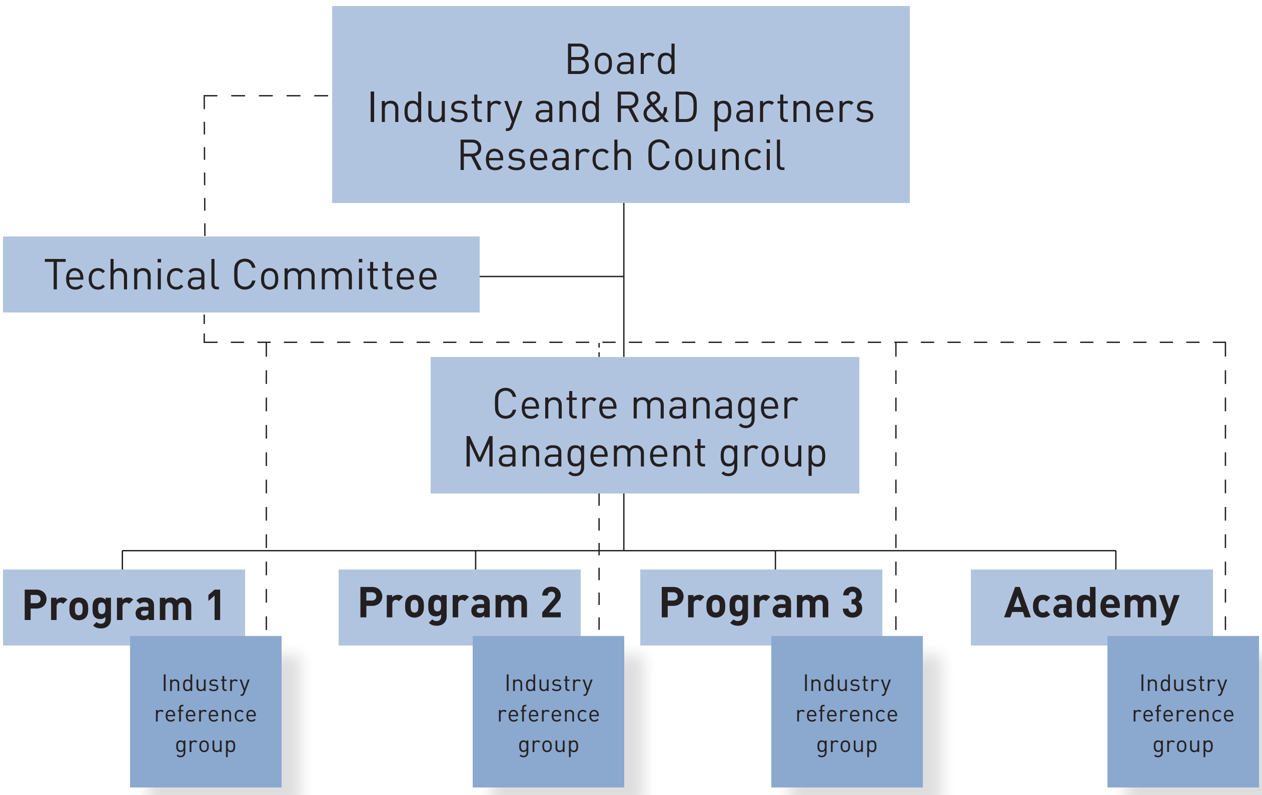
Project-based Reference Groups (RG) with technical specialists from the oil companies are established and provide advice and project supervision.

The industry involvement through the Board, the Technical Committee and the Reference Groups is essential for the innovation process. Innovation comes from intensive cooperation between industry experts and R&D personnel.

Project research management and coordination is provided by both Programme Managers and Project Managers.

A Score Card developed jointly by the Partners is used to perform an industrial evaluation of each project and of the Centre as a whole twice a year. This provides valuable feedback to the project and Centre's management and is used to direct the R&D for innovation.

Centre organisation



Budgets and Financial Matters

The Centre has a budget of NOK 42 million per year, funded by NOK 10 million from the Research Council of Norway, NOK 30 million from the participating oil companies and NOK 2 million from the Research Partners.

Operating cost 2014: NOK 47 million, including transfer from previous years.

Seminar

A two-day seminar with 60 participants from the participating oil companies, the Research Council and the Research Partners was successfully held at the Sola Strand Hotel, near Stavanger.

All the major project results were presented and discussed. The seminar is an important forum for a dialogue between the industry and researchers concerning key results and their applications.

A similar seminar will be arranged in 2015.

People in DrillWell

Drilling and Well Centre for Improved Recovery

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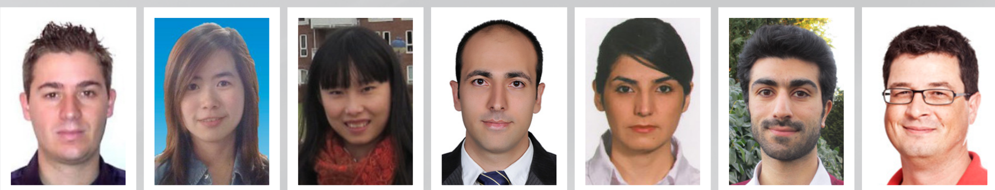

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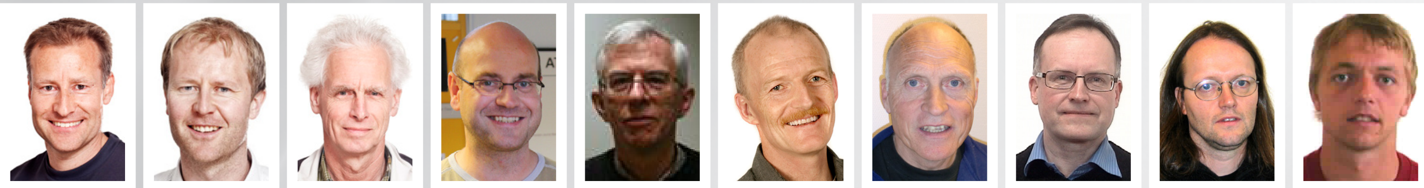

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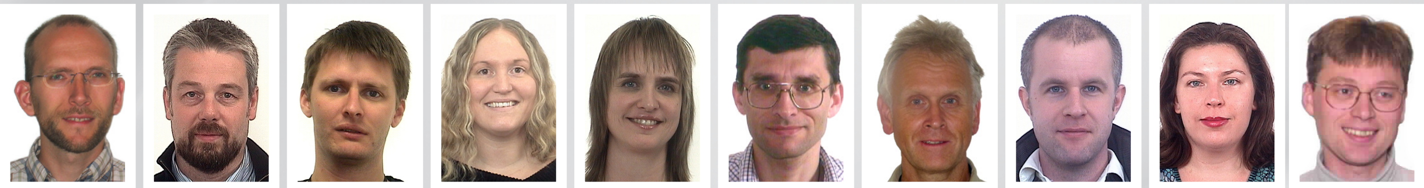

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H. B. Siahaan, K.S. Bjørkevoll and J. E. Gravdal, "**Possibilities of Using Wired Drill Pipe Telemetry During Managed Pressure Drilling in Extended Reach Wells**", presented at the SPE Intelligent Energy Conference and Exhibition, Utrecht, April 1-3, 2014.

K. Kullawan, R.B. Bratvold and J.E. Bickel, "**Value Creation with Multi-Criteria Decision Making in Geosteering Operations**", presented at the SPE Hydrocarbon Economics and Evaluation Symposium held in Houston, May 19-20, 2014.

E. Cayeux, B. Daireaux, E.W. Dvergsnes, H. Siahaan, and J.E. Gravdal, "**Principles and Sensitivity Analysis of Automatic Calibration of MPD Methods Based on Dual-Gradient Drilling Solutions**", presented at the SPE Deepwater Drilling and Completions Conference held in Galveston, Texas, USA, September 10-11, 2014.

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Ekofisk Complex. Press Photo: ConocoPhillips

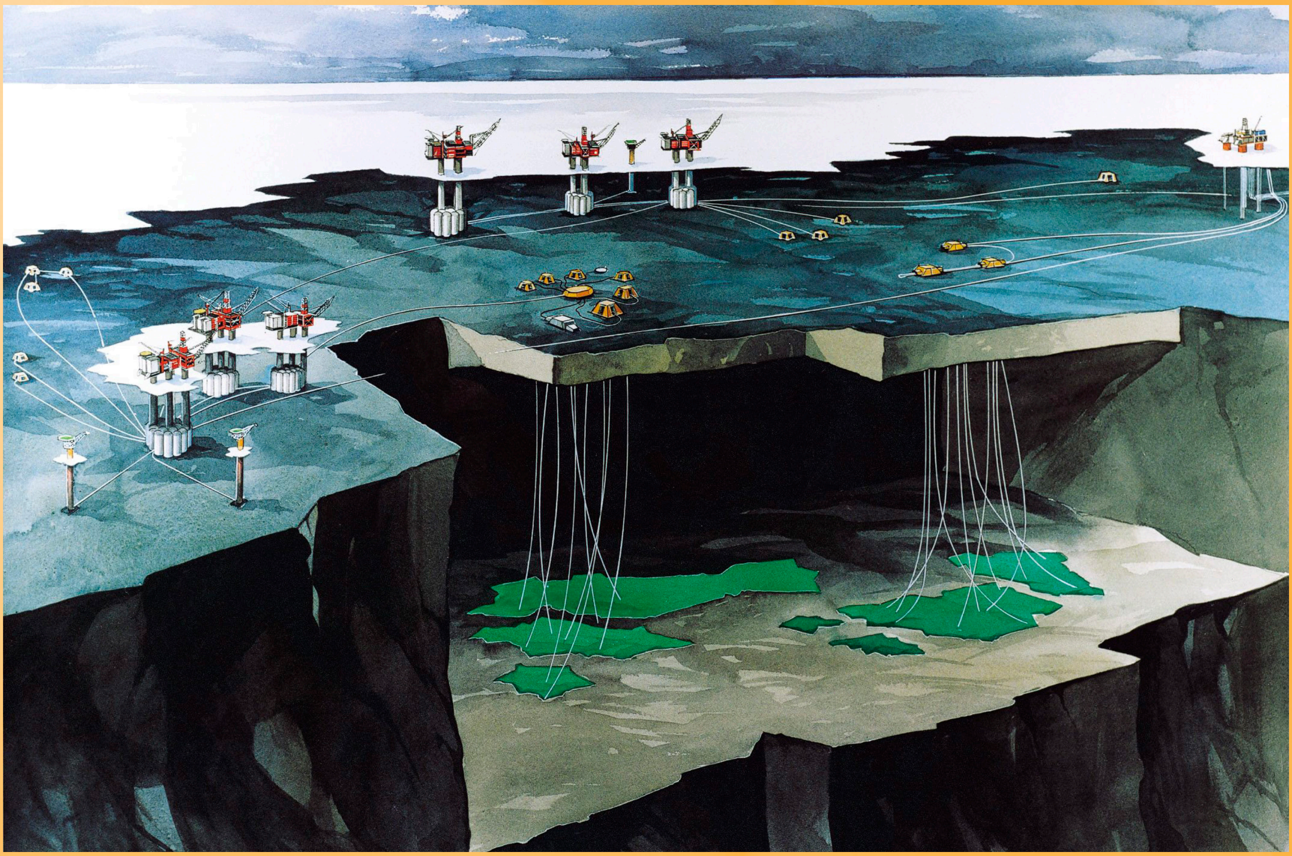

Illustration of the Tampen Area. Photo: Statoil

Johan Sverdrup

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Production start-up is scheduled for end 2019. The field will be developed in phases. The first phase involves the establishment of a field centre consisting of four platforms.

- Located on the Utsira Height in the North Sea, 155 kilometres west of Stavanger
- Oil from the field will be piped to the Mongstad terminal in Hordaland. The gas will be transported via Statpipe to the Kårstø processing plant in North Rogaland
- First-phase investments estimated at NOK 117 billion (2015 value)
- Total production revenues of NOK 1,350 billion over 50 years
- Corporation tax payable to the Norwegian state calculated at NOK 670 billion
- Daily production during first phase estimated at 315,000 – 380,000 barrels per day
- Peak production estimated to reach 550,000 – 650,000 barrels daily
- Water depth is 110 - 120 metres; the reservoir is located at a depth of 1900 metres
- The field will be operated by electrical power generated onshore

Illustration of Johan Sverdrup. Photo and text: Statoil

DrillWell
DRILLING AND WELL CENTRE FOR IMPROVED RECOVERY

Annual Report 2014

Drilling and Well Centre for Improved Recovery

VISION

Unlock petroleum resources through better drilling and well technology.

OBJECTIVE

Improve drilling and well technology providing improved safety for people and the environment and value creation through better resource development, improved efficiency in operations and reduced cost.

Cost reduction

Innovative drilling and well technology is needed to reduce exploration and development costs, as well as well plugging and abandonment.

Improved recovery

Improved wells at lower cost will imply higher recovery of oil and gas by increasing the number of wells and their productivity.

Efficient field development

Improved wells at lower cost will imply cost-efficient field development. Today the wells represent 50-60% of the field development cost.

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Visit our website www.drillwell.no for more information

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