Department of Petroleum Engineering and Applied Geophysics

Annual Report 2013

NTNU – Trondheim
Norwegian University of
Science and Technology

CONTENTS

Department of Petroleum Engineering and Applied Geophysics

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01.01.13 – 31.07.13

Head of Department:	Jon Kleppe
Deputy Head of Department:	Martin Landrø
Head of Administration:	Sylvi Vefsnmo

01.08.13 – 31.12.13

Head of Department:	Egil Tjåland
Deputy Head of Department (research):	Ståle Emil Johansen
Deputy Head of Department (education):	Sigbjørn Sangesland
Head of Administration:	Sylvi Vefsnmo

Cover photo: © Egil Tjåland
Boltana-antiklinalen in Pyreneene

GREETINGS FROM THE DEPARTMENT HEAD

It has been an exciting year for the Department of Petroleum Engineering and Applied Geophysics, a year of transition and growth. In July of 2013, Professor Jon Kleppe stepped down as department head after more than 13 years at the helm. The department has benefited tremendously from his wise and distinguished leadership. One of his achievements during his leadership was to strengthen international master studies with a subsequent transition of Norwegian to English as teaching language. This transition is now taken for granted at our Faculty, but at the time when Jon introduced the concept it was rather revolutionary. Well done Jon!

Professor Bjørn Ursin turned 70 years in September and then changed his status to Professor Emeritus. In June Bjørn celebrated his anniversary in Ainsa, Spain, together with close friends and colleagues. Bjørn has had an outstanding career in geophysics research, and has been working at our department for more than 30 year. Many a career in geophysics has been initiated from the inspiration of Bjørn. We look forward to a continuing research career in your new position.

This year we have got two new colleagues – Lisbeth Hultmann, who works as a study coordinator and Patrick Reurink, who works as a project coordinator at the IO-center. Welcome, to both of you!

On August 1st of 2013 I took over as departmental head. I really look forward to lead a department with so much enthusiasm, experience and talent.

I now want to highlight some of the major achievements and results made at the department during the last year.

The year 2013 was a year of extremes. Not least because of a record number of 120 MSc students graduated from our department. Of these students around 50% came from other countries than Norway, making our study truly international. The large number of graduations this year makes us the biggest "producer" of MSc degrees in petroleum engineering and geophysics in the world.

In 2012 our student intake for the Norwegian applicants more than tripled compared to the previous year. Therefore we were even more delighted when we in 2013 got a 15% increase in the number of primary applicants compared to 2012! This made our study the most competitive technical study in in Norway with close to 10 applicants per study place. The future looks bright!

Our department became members in a new national research center, the Research Center for Arctic Petroleum Exploration (ARCEx). The center is located at the University of Tromsø, and our contribution will mainly be within geology and geophysics. We look forward to a lot of good research in a truly national and international collaboration.

An important part of the research at our department is done by our PhD candidates together with their supervisors. A total number of 9 PhD's were awared in 2013, and we would like to congratulate them all with their achievements. One of the ongoing PhD candidates, Sissel Grude, won the prestigious "Young Scientists Award" from the Sustainable Earth Sciences conference in Pau, France in October. Congratulations!

The Center for Integrated Operations completed another 7th year of research in 2013, supported by the Research Council and 14 oil companies and service companies. In September the now very respected IO-conference (IO13) was arranged in Trondheim with close to 300 participants. This year the keynote speaker was one of our 1992 alumnus, Paal Kibsgaard, who now is CEO of Schlumberger.

The ROSE seminar (ROck SEismic) was arranged for the 13th time in May. The seminar has now more than 25 supporting companies, and a record attendance of around 80 followed technical presentations and workshops for 4 days.

In August the regular SVALEX field course was followed by a new field course called "SVALEX US" where around 60 students and 20 professors from University of Texas, Austin participated in a multidisciplinary geoscience and petroleum engineering course at Svalbard in the High Arctic. The course lasted for 6 days and was a follow-up of the Memorandum of Understanding made by NTNU and the University of Texas, Austin from 2012.

Finally I would like to express my gratitude to all members of the department for their contribution to keep our department at the highest standard in cutting edge research and education quality.

Egil Tjåland
Head of Department

Staff

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Head of Administration: Sylvi Vefsnmo

Scientific Staff

Professors
Børge Arntsen, Harald Arne Asheim, Michael Golan, Jon Steinar Gudmundsson, Rune Martin Holt, Tom Aage Jelmert, Ståle Emil Johansen, Jon Kleppe, Martin Landrø, Arild Rødland, Sigbjørn Sangesland, Alexey Stovas, Ole Torsæter, Bjørn Ursin, Curtis Hays Whitson

Associate Professor
Pål Skalle, Egil Tjåland (until 31.07.13)

Assistant Professor
Jan Ivar Jensen, Helge Langeland, Erik Skogen

Adjunct Professors
Lasse Amundsen, Per Åge Avseth, Andreas Bauer, Per Arne Bjørkum, Reidar B. Bratvold, Erling Fjær, Tor-Berge Gjersvik, John-Morten Godhavn, Vidar Hepsø, Ketil Hokstad, Odd Steve Hustad, Lars Høier, Cai Puigdefabregas, Philip S. Ringrose, Jan Åge Stensen

Adjunct Associate Professors
Stein Inge Dale, Jørg Ebbing, Jan Steinar Rønning

Project leader IO-center
Jon Lippe

Technical and administrative staff

Administrative Staff
Anne-Lise Brekken, Solveig Johnsen (IO-center, until 04.08.13), Lisbeth Hultmann (from 05.08.13), Patrick Reurink (IO-center, from 30.09.13), Tone Sanne, Turid Oline Uvsløkk, Sylvi Vefsnmo, Madelein Wold

Technical Staff
Knut Reitan Backe, Gunnar Bjerkan, Terje Bjerkan, Håkon Myhren, Roger Overå, Lars Johan Sandvik, Åge Sivertsen, Erlend Våtevik

Temporary scientific staff

Post Doctor/Research Scientist
Bastien Dupuy, Raheleh Farokhpoor, Nanji Hadia, Qi Hao, Md Aminul Islam, Aleksander Juell, Uduak Akpan Mme

Doctoral Students
Katherine Rose Aurand, Alena Ayzenberg, Brahim Abbad, Mohammad Ashrafi, Hadi Mohammed Balhareth, Daniel Martin Lewis Barker, Mayembe Bartolomeu, Eldar Baykiev, Mathias Chakib Rodriguez Bellout, Andreas Nicolas Berntsen, Tuhin Bhakta, Mohammad Hossain Bhuiyan, Bjørn Astor Brechan, Dipankar Chowdhury, Jesus Alberto De Andrade Correia, Glenn Kåre Gabrielsen, Amir Ghaderi, Sohrab Gheibi, Ashkan Jahanbani Ghahfarokhi, Mohammad Ghasemi, Sissel Grude, Luky Hendraningrat, Mohammad Sohrab Hossain, S. M. Ishtiak Hossain, Hamid Hosseinzade Khanamiri, Kjetil Eik Haavik, Narjes Jafariesfad, Wojciech Jurus, Rasoul Khaledialidusti, Mohammad Ali Taghipour Khadrbeik, Anders Fredrik Kiær, Morten Ivar Kolstø, Shidong Li, Yi Liu, Lutz Mütschard, Mehran Namani, Aziz Nasuti, Martin Panzner, Torbjørn Pedersen, Szczepan Polak, Espen Birger Raknes, Siroos Salimi, Samad Valipour Shokouhi, Yaser Souraki, Mansour Soroush, Milan Edvard Wolf Stanko, Anna Magdalena Stroisz, Dawid Szewczyk, Amir Taheri, Anastasiya Tantsereva, Olena Tiapkina, Jon Marius Venstad, Sthener Rodrigues Vieira-Campos, Wiktor Waldemar Weibull, Torgeir Wiik, Sandra Witsker, Dapeng Zhao

Accounts 2013

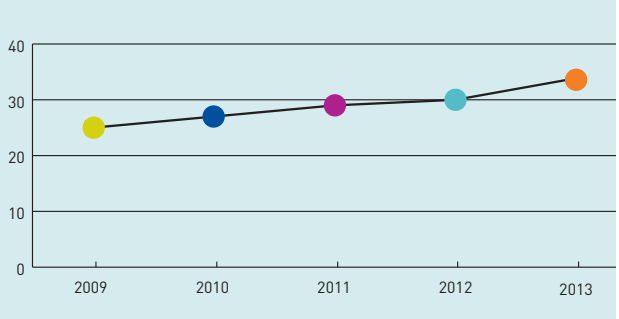
The department has three main sources of income:

- Regular income from the University
- Strategic funding from the University
- External projects

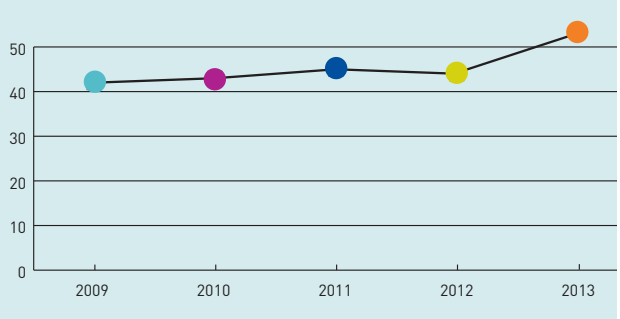
The Government University funding, including strategic projects was about 34 million NOK in 2013. These funds are mainly used for salaries to the permanent staff, contribution to research projects and to investments and regular operations of the department.

The department has a substantial income from external contributions of about 54 million NOK. The main costs on the projects are related to salary for PhD candidates and Post Doctors. The main contributor to the external research activity is the Norwegian Research Council and the oil industry. The department has several joint industrial programs with industry partners from countries in Europe, North-America, South America, Africa and Asia. External funding from commissioned research was approximately 1% in 2013.

Sources of Funding	Funding (million NOK)
University funding	33,8
The Norwegian Research Council	16,9
Commissioned Research (several)	1,4
EU	0
Contribution from industry	35,7
Totally	87,8



Budget Allocation from NTNU (Mill. NOK).



Funding from External Sources (Mill. NOK) (Not Including IO Center).

Awards 2013

Young Scientist Prize 2013
PhD fellow Sissel Grude

Sissel Grude was presented this prize at the conference Sustainable Earth Sciences in Pau, France, where she presented a paper with the title: "Pressure Effects Caused by CO_2 Injection in the Snøhvit Field". The organizer EAGE – European Association of Geoscienctists & Engineers aims through the Young Scientist Prize to encourage further research and development on sustainability and earth science. The terms for this prize are, among others, that contributions should offer an innovative approach to sustainable use of geological resources, and through the theme that the conference concentrates on.

Center for Integrated Operations in the Petroleum Industry

The IO Center is a center for research-based innovation with research institutions and industry working closely together. The center contributes to **better and faster decisions through enhanced integration of people, processes and technology**, and is a leading international research center on integrated operations in the petroleum industry.
The industry partners in 2013 have been: BP, ConocoPhillips, Eni, GDF SUEZ, PETROBRAS, Shell, Statoil, Total, Aker Solutions, DNV GL, FMC Technologies, IBM, Kongsberg OGT and SKF. In addition TU Delft, Boston University, the Central University of Central Florida, UC Berkeley, IBM Research, Carnegie Mellon University, Federal University of Santa Catarine and Stanford University are international academic cooperators. The center is funded by the partners and the Research Council of Norway until 2015.

Integrating people, processes and technology

The IO Center has a wide research focus on integrated operations, and is conducting research across the following projects:

- IO Teamwork and Capabilities
- Integrated Planning and Logistics
- Proactive Management of Safety and Environment
- Production Optimization and Subsurface IO
- System Integrity and Dynamic Risk Assessment
- Future Telemedicine in Oil and Gas

For a full overview of activities and results, visit the IO Center website at **www.iocenter.no**

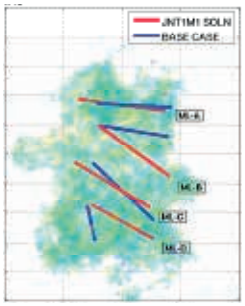
Production optimization at PETROBRAS

The IO Center has developed a new method for computerassisted production optimization which has been implemented and tested on Marlim field FPSOs by PETROBRAS, leading to **increased production and 35 million USD increased yearly income**. Also other oil companies in the IO Center (Statoil, TOTAL, BP and GDF SUEZ) are working with production optimization by using similar methods and tools. The expected potential for increased production is 1 to 4 percent, which will generate huge extra profits, since the cost of implementation is small compared to the benefits.

The IBM Thomas J. Watson Research Center has contributed to the development of optimization methods and software solutions.

Well placement optimization at Martin Linge oil reservoir

The IO Center has developed a significant array of methodologies to increase oil recovery through optimized reservoir management and planning. Our focus in Phase II of the IO Center has been to effi ciently apply these methodologies to real field cases and operational challenges faced by the petroleum industry. In close collaboration with operator and IO Center partner, TOTAL E&P, we have successfully applied a methodology that optimizes well locations to increase the recovery of the Martin Linge oil reservoir.



In collaboration with the reservoir team, well performances from the suggested well trajectories are studied and evaluated with respect to drilling concerns and model uncertainties. This project has relied on a steadfast commitment to collaborative work between the reservoir and research team. Collaboration between the teams was facilitated by an effi cient sharing of model and strategy information, and a strong emphasis on analysis and dissemination of results.

Key figures 2013	No.	Man-years
Research scientists:	83	19,2
PhD-students:	12	12
Postdoctoral fellows:	4	3
Master students:		15
Journal papers:		16
Conference papers:	35	
Technical reports:		65
Total revenue		56,7 MNOK

International Conference on Integrated Operations in the petroleum industry – where science and business meet
IO13 was the 9th International Conference on Integrated Operation in the petroleum industry organized by the IO Center and took place on the 24th and 25th of September in Trondheim. Key note speakers included Paal Kibsgaard, CEO of Schlumberger and Solange da Silva Guedes, E&P Executive Manager of PETROBRAS. The next IO Conference is on September 30 – October 1, 2014. More info: **www.ioconf.no**

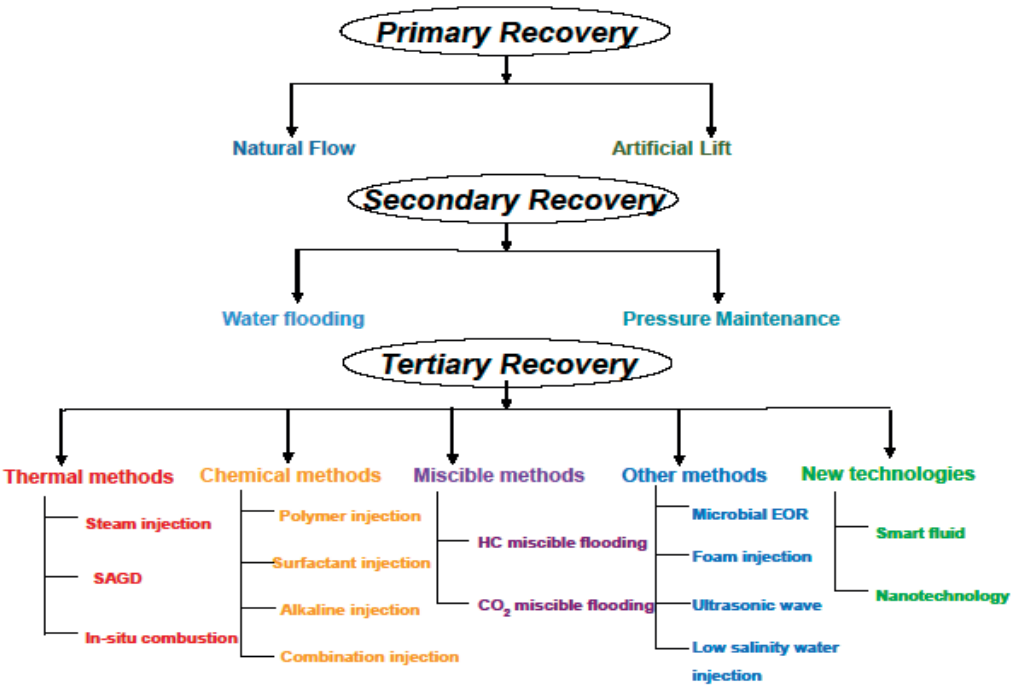
WORKSHOP IN GDANSK

The Department held its yearly workshop in Gdansk Poland in June 2013. Around 30 of the Department staff, technical-administrative, PhD research fellows and post doctor personnel participated with presentations of their activity.

Nanofluid Injection for Enhanced Oil Recovery

Enhanced Oil Recovery (EOR)

As it has become more difficult to find new reservoirs for oil and gas production, the industry has shifted focus to researching ways to extract more hydrocarbons out of reservoirs already in production. Enhanced oil recovery (EOR) is a term used to describe these techniques that increase the amount of crude oil that can be extracted from an oil field. EOR is sometimes called improved oil recovery or tertiary recovery, although most EOR techniques can be applied to a reservoir at any stage during its life. At NTNU, we are interested in investigating the potential of using nanofluids as a new EOR agent.



What are nanofluids?

Nanofluids are composed of nanoparticles suspended in fluids. A nanoparticle is defined as a particle with a size range of 1 nm to 100 nm. At NTNU, we typically suspend the nanoparticles in a liquid such as saltwater. Our nanofluids have nanoparticle concentrations ranging from 0.01 to 1 weight percent.

Why nanofluids for EOR?

There are many reasons why nanofluids show promise as an EOR agent. Some of those reasons are listed here:

- Have been shown to increase oil recovery from the reservoir (discussed in detail in Our Research section below)
- Can use existing infrastructure already in place for traditional water flooding
- Already manufactured in mass quantities for other industries
- Low fabrication cost, especially compared to polymers and surfactants
- Ability to modify the particle surface to control properties such as hydrophilicity and salt tolerance
- Possibility to recycle the nanoparticles that flow through the reservoir

Nanoparticles (size, type, etc.)

Hydrophilic silica nanoparticles and nano-structured particles are the focus of this study for three main reasons: 1) they have been shown to improve oil recovery in previous studies[1,2,3,4,] 2) they are typically cheaper to manufacture and purchase compared to other nanoparticles such as titanium dioxide and 3) they are composed of over 99% silicon dioxide (SiO_2), which is the main component of sandstone, so they are environmentally friendly especially when compared with other chemical agents such as polymers.

Previous studies have found that hydrophilic silica nanoparticles increase oil recovery[1,2,3,4].The surface area to volume ratio can be very high for nanoparticles, enhancing the chemical reactivity of the nanofluid and resulting in the effect that fewer nanoparticles are needed to achieve similar functions of other EOR agents such as surfactants and polymers.

Our research

Nanoparticle has huge surface area, for 7nm nanoparticle, specific surface area is 300 m^2/g. So nanoparticles are easily adsorbed inside sandstone, which result in change of reservoir properties like wettability.

Injection of hydrophilic nanoparticles into neutral wet Berea sandstone can change wettability to water wet, and the higher concentration of nanoparticles the more water wet will the reservoir be. (Figure 1)

Nanofluid can reduce IFT between oil and water and make porous media more water wet, and also has ability to stabilize emulsion. In visualization experiments of nanofluid flooding performed in glass micromodels, we can see the oil saturation difference before and after nanofluid injection. (Figure 2)

In addition to interfacial tension reduction and wettability alteration microscopic diversion (log jamming)1 is an important mechanism. (Figure 3)

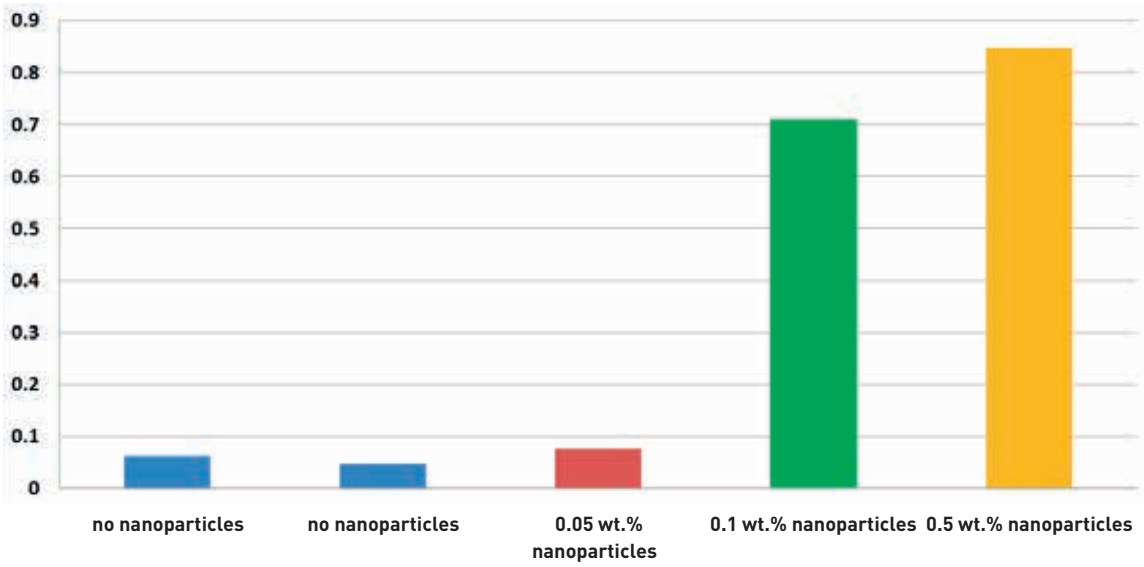


Figure 1: Wettability Index for Neutral Wet Cores Treated by Hydrophilic Nanoparticles

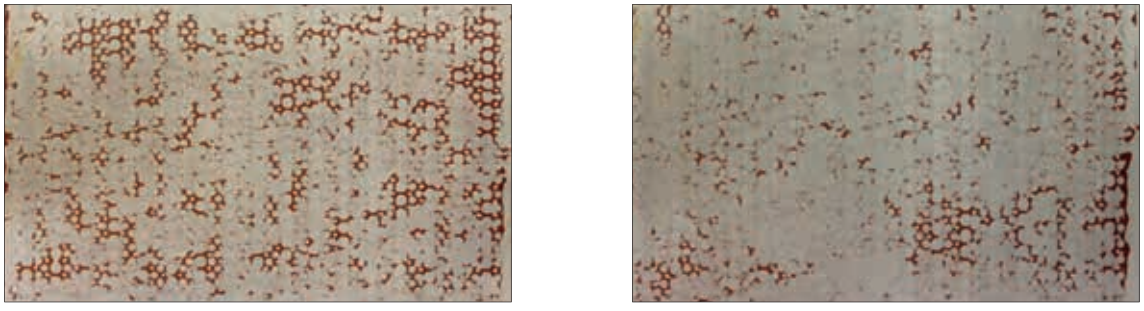


Figure 2: Oil saturation (dark brown) before (left) and after (right) nanoflooding.

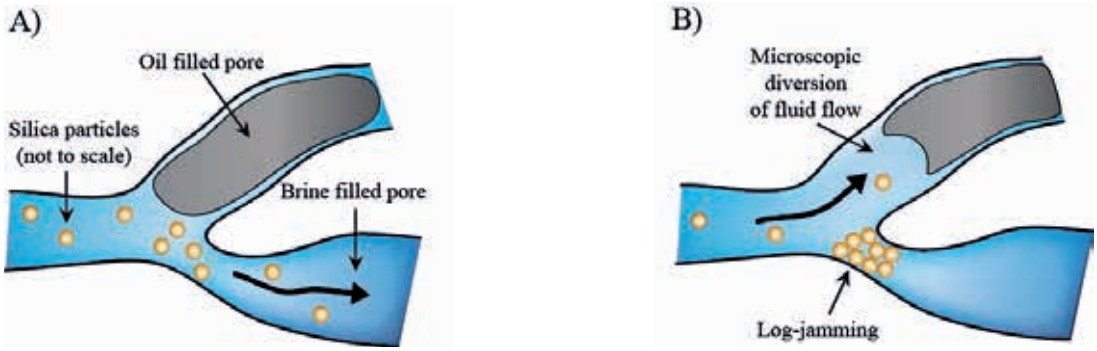


Figure 3: Schematics of microscopic diversion.

The figure above (from Aurand et al. 20141) gives our interpretation of the log-jamming mechanical mechanism leading to microscopic diversion of the fluid flow and subsequent additional oil recovery. A) The nanofluid initially flows along the path of least resistance. Oil in untouched pores provides resistance to brine and nanofluid sweeps because of its higher fluid viscosity. B) Eventually, the silica particles may block a previously available pore throat. This is especially likely if there is a constriction in the pore diameter, causing the particles to crowd together as they attempt to squeeze through the opening. This could lead to nanoparticles creating a relatively impassable wall via a process called "log-jamming". This would cause the injected fluid to be diverted to the other pore throats. The increase in pressure as a result of decreased permeability would allow the fluid to overcome the force needed to mobilize the viscous oil.

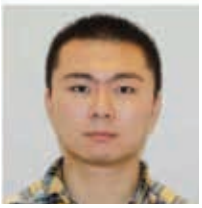
The project on nanofluids for EOR at NTNU is presently scheduled to last till 2018.

The Team

Ole Torsæter

Luky Hendraningrat

Katherine Aurand



Shidong Li

References

1. Aurand, K.R., Dahle, G.S. and Torsæter, O., 2014, Comparison of oil recovery for six nanofluids in Berea sandstone cores. Paper presented at the International Symposium of the Society of Core Analysts held in Avignon, France, 8-11 Sept. 2014, 12 p.
2. Hendraningrat, L., Li, S. and Torsæter, O., 2013a, A coreflood investigation of nanofluid enhanced oil recovery in low-medium permeability Berea sandstone. Paper SPE 164106 presented at the SPE International Symposium on Oilfield Chemistry held in the Woodlands, Texas, USA, 8 – 10 April 2013, 14 p.
3. Hendraningrat, L., Li, S. and Torsæter, O., 2013b, Enhancing Oil Recovery of Low-Permeability Berea Standstone through Optimized Nanofluids Concentration. Paper SPE 165283 presented at the SPE Enhanced Oil Recovery Conference held in Kuala Lumpur, Malaysia, 2 – 4 July 2013, 10 p.
4. Li, S. and Torsæter, O.: An Experimental Investigation of EOR Mechanisms for Nanoparticles Fluid in Glass Micromodel. Paper presented at the International Symposium of the Society of Core Analysts held in Avignon, France, 8-11 Sept. 2014, 12 p.

IPT a member of the ARCEx consortium

The Arctic in general and the Barents Sea in particular, hold potentially large hydrocarbon resources. The Barents Sea area comprises a wide range of sedimentary basin systems, each characterized by a complex tectonic history involving a variety of geological processes operating at different temporal and spatial scales. Among these are overlapping Paleozoic orogenies (Timanian, Uralian, Caledonian) preceded multiple rift episodes (Carboniferous, Late Jurassic-Early Cretaceous, and Late Cretaceous-Paleogene), eventual breakup with Greenland to the west and Lomonosov Ridge to the north, and Cenozoic uplift and erosion. There are many uncertainties in understanding the petroleum resource potential of these areas. Future hydrocarbon exploration must be based on a better understanding of fundamental, dynamic processes behind the formation and geological evolution of individual sedimentary basins in the Barents Sea region and their impacts on the petroleum systems. Integrating sound environmental practices based on the understanding of Arctic ecosystems and species sensitivity to petroleum activities improves public acceptance for the opening of new areas to resource exploration.

The Research Centre for ARCtic Petroleum Exploration (ARCEx) aims primarily at improved knowledge of petroleum resources in northern and Arctic areas, with the complementary aim of providing essential knowledge and methodology for eco-safe exploration in the high north. Eco-safe refers to the use of best available technology and practices in order to minimize impacts and risks to the Arctic environment.

This will be achieved through the following objectives:

- Enhance the understanding of large-scale processes of sedimentary basin formation and evolution of the Barents Sea and Arctic, and their impacts on petroleum systems.
- Secure correlation of geological events over large distances in diverse geological environments of the Arctic.
- Establish petroleum systems and play concepts for the different basins.
- Assimilate new ecosystem knowledge for the different basins into advanced impact and risk analysis methodologies.
- Develop technology for eco-safe exploration in the Arctic.
- Create a research-based education and training program based on the scientific themes of the Centre.
- Communicate results from the Centre to scientists, decision makers and the general public.
  The Centre, based at Norway's northernmost University will, in 8 years, establish itself at the forefront of scientific excellence in Arctic petroleum geology and geophysics. ARCEx will become a resource of highly qualified personnel with specialized training for eco-safe petroleum exploration in the Arctic.

Partners in the consortium:

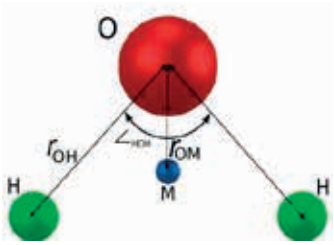
- Host Institution: University of Tromsø – Faculty of Science and Technology (UiT-NT)
- University of Tromsø - Faculty of Biosciences, Fisheries and Economics (UiT-BFE)
- Akvaplan-Niva (APN)
- Northern Research Institute Tromsø (NORUT)
- The University Centre in Svalbard (UNIS)
- University of Oslo – Department of Geosciences (UiO-Geo)
- University of Bergen – Department of Earth Sciences (UiB-Geo)
- Norwegian University of Science and Technology (NTNU)
- The Geological Survey of Norway (NGU)
- University of Stavanger- Centre for Risk Management and Societal Safety (UiS-SEROS)
- International Research Institute of Stavanger (IRIS)

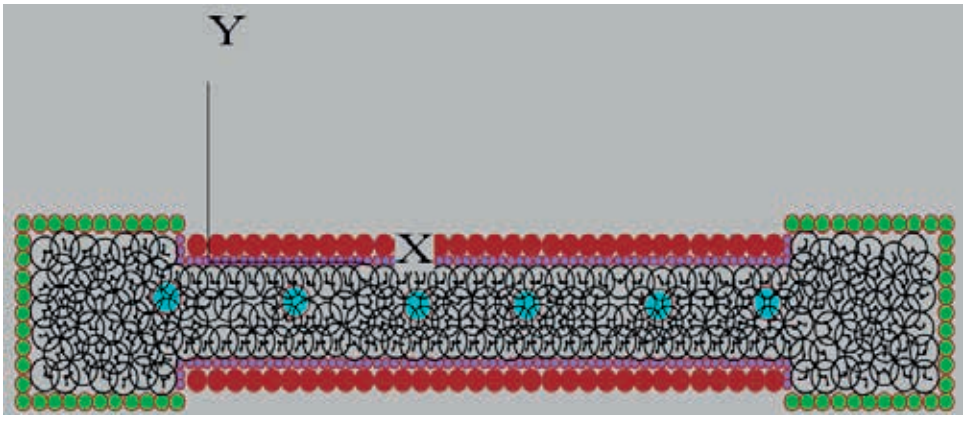
New insights in rock physics from numerical and laboratory simulations

With continued developments in seismic processing and acquisition technologies (such as AVO / AVA and 4D seismic), rock physics has during recent years become an increasingly more important part of seismic interpretation. This means that there is a need for development of better rock physics models. These should be built on fundamental knowledge of how rock composition and texture as well as boundary conditions such as stresses, pore pressure and temperature influence various seismic attributes.

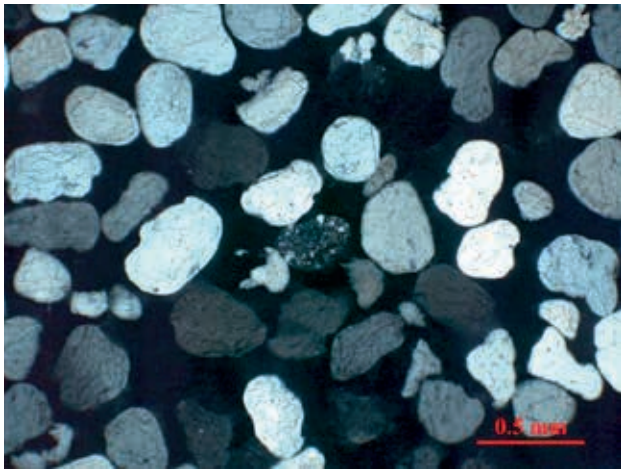
Current rock physics research at IPT is aimed at improving our understanding of unconsolidated sands and clay rich sediments. Unconsolidated sands play important roles as reservoirs for oil and gas production as well as for CO_2 sequestration. Clay and clay rich shales constitute a significant part of the overburden, and thus have a large influence on seismic travel times. There is an obvious direct influence, because seismic waves have to pass through the overburden twice when they are reflected from the top of a reservoir. Indirectly, stress changes in the overburden caused by fluid withdrawal in depleting or inflating reservoirs cause changes in travel times and reflectivities. These serve as fingerprints of depleted pockets or inflated zones in 4D seismic, providing guidelines to in-fill drilling operations, and assisting in monitoring of CO_2 storage reservoirs.

Laboratory experiments, performed in cooperation with the Formation Physics department in SINTEF Petroleum Research, form the basis for our rock physics research. Analytical and numerical rock physics and geomechanics model development and modelling is linked to experimental observations.





Discrete element model for simulating mechanical behaviour of water in clay. Water molecules (as shown in the insert, black in the lower figure) are embedded between two solid plates with charged surfaces (brown and purple circles). Notice the ordering of water close to the surfaces. The blue circles represent sodium ions, whereas the preen circles form an uncharged membrane to keep the water in place. Compression tests are performed by moving the upper surface towards the lower in the Y-direction, while shear tests are performed by moving the upper surface in the X-direction. (From PhD of Kolstø, 2013)



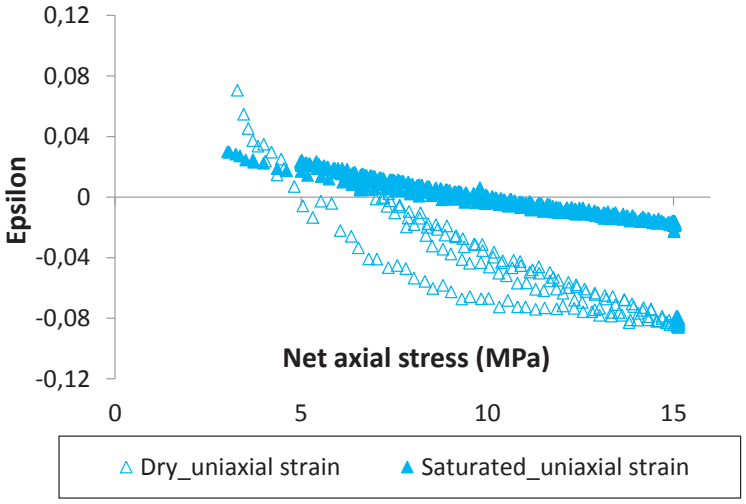
Thin section image of Ottawa sand, used for experiments on stress-induced anisotropy and effects of fluid substitution.

Unconsolidated sand

Anisotropic wave velocity measurements have been performed on sands and sand-clay mixtures, using a specially designed oedometric cell as well as a triaxial apparatus. The experiments on sand revealstress dependent anisotropy, adding to a small textural anisotropy caused by the packing of the sand. The full anisotropy of the sand is measured and quantified in terms of the so-called Thomsen parameters, ε (P-wave anisotropy), γ (S-wave anisotropy) and δ (move-out parameter). In particular, the effect of fluid saturation on velocities and on anisotropy parameters have been addressed and compared to existing theoretical models. A somewhat surprising result was that the ultrasonic shear modulus differed between dry and water-saturated sand, apparently violating a fundamental assumption made in conventional fluid substitution analysis. A literature survey confirmed similar observations by several researchers, although the discrepancies have never been highlighted in publications. Our work, performed largely as a part of the Ph. D. Thesis of Mohammad Hossain Bhuiyan (to be completed in 2014), points to dispersion as the main source of this discrepancy. In fact, frequency dependence according to the poroelastic Biot theory seems to provide a valid quantitative explanation.

Water in clay and shale

Experiments demonstrate that P- and S-wave velocities in clays and clay rich shales are strongly sensitive to the pore water. Pores in clays are however small – typically on the nanometer scale, which means that they are not much larger than water molecules themselves. This implies that the interaction between water and mineral surfaces play a more important role than in more permeable soils and rocks, such as sand and sandstones. Molecular dynamics simulations have shown that water inside clay minerals and near mineral surfaces has an ordered structure. Such water is considered as bound or adsorbed water, and is likely to have direct influence on elastic properties. In his Ph. D. work, Morten Kolstø (2013) used a discrete element method (PFC; trademark of Itasca), initially developed for modelling the mechanical behaviour of granular media, to simulate the structure but and the inherent stiffness of bound water. Its normal and shear stiffness was found to depend on mineral surface charge density and on salinity of the pore fluid. A simple rock physics model that contains bound water properties as input parameters has been used to compare with experimental data, largely on pure systems of compacted kaolinite and compacted smectite.



P-wave anisotropy vs stress for loading – unloading sequences on dry and water-saturated sand in uniaxial strain (oedometric) experiments. Increasing axial stress leads to increasingly negative anisotropy. This stress-induced anisotropy effect is, as expected, larger in dry than saturated sand. (From PhD work of Bhuiyan)

Further work

Rock physics work at IPT is led by Professor Rune M Holt and Professors II Andreas Bauer, Erling Fjær, and Per Åge Avseth. In 2013, two new Ph. D. students (Dawid Szewczyk and Sohrab Gheibi) started their work on rock physics and geomechanics of CO2 storage. There will also be continued work in the area of shale rock physics, including studies of anisotropy, dispersion and static vs dynamic mechanical properties.

DrillWell

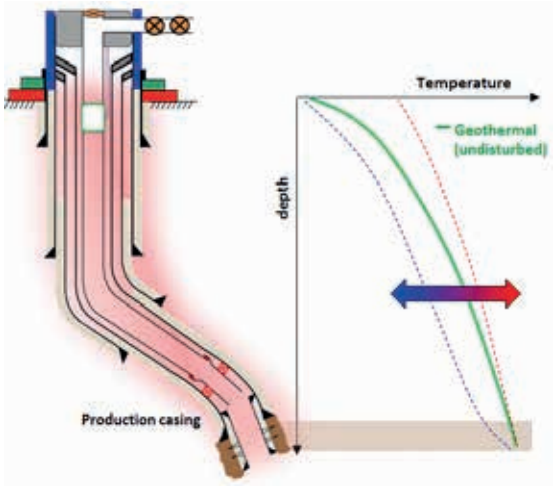
The Drilling and Well Centre for Improved Recovery (DrillWell) is an industry-driven collaboration and innovation environment with the industrial partners funding, prioritizing and directing R&D efforts towards their requirements and challenges. The centre headed by IRIS, is funded by six industry partners and the Research Council of Norway as a Centre for Research-based Innovation (SFI). Reference is made to the annual report; http://drillwell.no/DrillWell/files/2013_drillwell.pdf

One of the activities in the DrillWell program is cost efficient and safe plugging and abandonment of wells (P&A).

Cement Sheath Integrity During Thermal Cycling

PhD Candidate: Jesus De Andrade

Well cement is placed into the annulus between casing and formation to provide structural support and zonal isolation through the entire well service lifetime. The success of the primary cement jobs starts with the placement of the cement sheath. This means that all cuttings and mud in the annulus are fully displaced. Mud channeling along the cement sheath adversely affects zonal isolation, as it provides a leak path for hydrocarbon. . After placement, cement setting properties have an important role in archiving cement sheath integrity. The cement curing process may be associated to shrinkage of the annular volume, which can lead to the initial development of cracks and de-bonding at the casing/cement and cement/formation interfaces. However, even if a good primary cement job is achieved, variations in temperature and pressure over the well lifecycle are likely to induce the same type

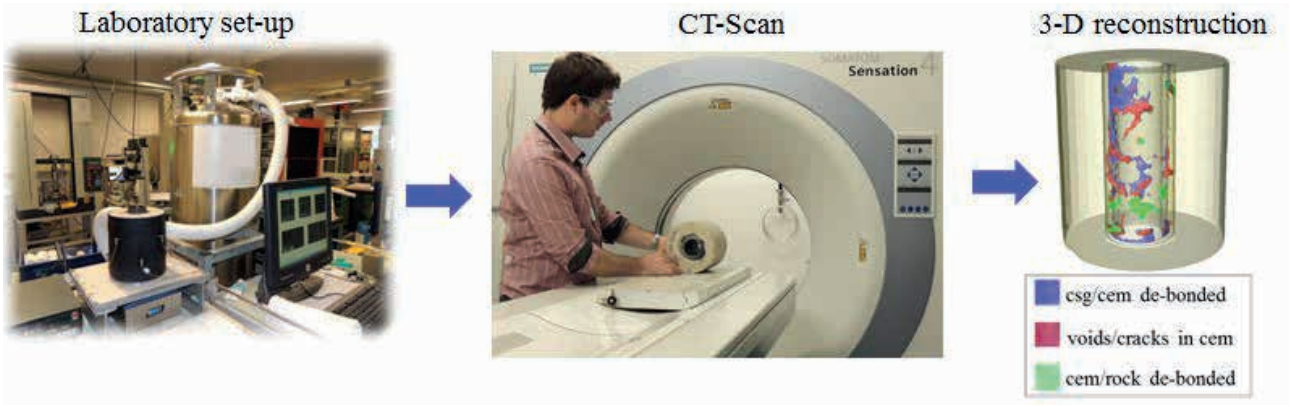


of failure mechanisms and threaten the sealing integrity. This old and known problem has recently raised the concern of many operators in the North Sea.

In the field, sonic and ultrasonic tools are typically used to verify the status of the cement sheath barrier. Nevertheless, there are challenges related to the reliability of these technologies. On the other hand, there are difficulties associated with reliably predicting failure of the annular cement sheath through computer modelling. This underlines the importance of gathering more information on this topic from experimental work.

Laboratory set-up

We have developed a new experimental methodology to investigate how thermal cycling affects annular cement integrity. Our procedure consists in using a set-up where temperature variations are applied to downscaled well sections (pipe-cement-rock). Debonding and radial cracking is monitored during the experiment, and the volumes and extents of cracks/debonding is mapped by computed tomography (Ct-Scan) methods after exposed to thermal cycling related loads.



This reveals how and when cement integrity fails during thermal cycling as a function of cycle and temperature profile – and how sensitive the process is to variables such as casing surface finish and stand-off.

PhD in the IPT drilling group

Torbjørn Pedersen

Life as a PhD at IPT

I started my PhD in the final quarter of 2012, so 2013 was my first real year as a PhD candidate at the department. It has been an intense and eventful year, which includes participation at the IBM best student recognition event 2013, the European Control Conference, the annual department seminar, and at the International Symposium on Dynamics and Control of Process Systems. Taking me respectively to Montpellier in France, Zürich in Switzerland, Gdansk in Poland, and Mumbai in India. If you want to see the world, do a PhD!

In April I was elected the leader of the interest organization for doctoral candidates at NTNU (DION). This means that I got to learn a lot about how the university is run, that I have attended a lot of meetings and hearings, and met many, many PhDs from all over NTNU. I have also seen that PhDs at NTNU really can influence on our own working environment, and that the distance to the central administration of NTNU is actually quite short.

PhD goal

The goal of my PhD is to push towards Holistic Automated Pressure and Flow Control for Underbalanced Drilling.

Traditional drilling operations have been characterized by a low degree of automation, and a sharp division between topside and well considerations. The goal of this project is to understand the limitations and possibilities given by automation of the underbalanced drilling process.

Figure 1: From left: Elin Alva Uppström (KTH), Jakob Schuldt-Jensen (DTU), Torbjørn Pedersen and Ida Enge (NTNU) at the IBM Best Student Recognition Event 2013.

Figure 2: Torbjørn at the IPT office

The International Association of Drilling Contractors (IADC) has defined underbalanced drilling (UBD) as "A drilling activity employing appropriate equipment and controls where the pressure exerted in the wellbore is intentionally less than the pore pressure in any part of the exposed formations with the intention of bringing formation fluids to the surface".

Two aspects of this definition are very important. The first is that the pressure is intentionally controlled to be less than the formation pressure; the second is that we have an intention of bringing formation fluids to the surface. This is very different from conventional drilling, where formation fluid inflow during drilling is unwanted and may even be dangerous.

This adds new challenges, including multi-phase transport with gas in the system, a highly non-linear system, and a full-scale separation plant.

I use model-based control to automate vital parts of the drilling operation. The main focus is flow and pressure modelling, as well as derivation of control algorithms.

I am currently working on using predictive models and measurements while drilling to predict disturbances before they reach the topside equipment.

Keywords: Underbalanced drilling, automation, process control, multi-phase flow, modelling.

Project group

My PhD is part of larger project called **Intelligent Drilling - Automatic Underbalanced Drilling Operations,** or simply iUBD.

At NTNU our group consists of four PhDs, one Postdoc, and four Professors split between the department of Petroleum Engineering & Applied Geophysics and the department of Engineering Cybernetics. We are also cooperating with researchers at the Statoil Research Centre, IRIS, the University of Stavanger, and at MINES ParisTech. The project is funded by the Norwegian Research Council (NFR) and Statoil ASA with project number NFR210432. Professor Lars Imsland at Engineering Cybernetics is the project coordinator.

We believe that Underbalanced drilling operations (UBD) will see increased use on the Norwegian Continental Shelf, as well as in the rest of the world. UBD is often used to minimize formation damage, but perhaps more importantly in a North Sea perspective is that UBD in many cases will be necessary to achieve desired production in depleting oil fields with vanishing pressure margins. UBD also enables online reservoir characterization while drilling.

The main research objective is to develop intelligent closed-loop control concepts for improved safety and efficiency of offshore underbalanced drilling operations. UBD with complete control over borehole hydraulics will be an enabling technology for getting access to reserves in mature fields which are unreachable with conventional drilling technologies. Moreover, such UBD technology will provide a number of other enhancements in safety and efficiency of drilling operations.

Modeling and Simulation of Production Systems

The research and teaching activities about computational modeling of hydrocarbon production systems were focused in 2013 on the following issues: model based production optimization, virtual metering and production allocation, modeling of water injection process and post hydraulic fracturing cleanup of shale gas wells, inline oil-water separation for subsea applications. The activities were carried out in 3 MSc and 4 PhD research projects (Sthener Vieira-Campos, Mayembe Bartolomeu, Wojciech Jurus and Milan Stanko).

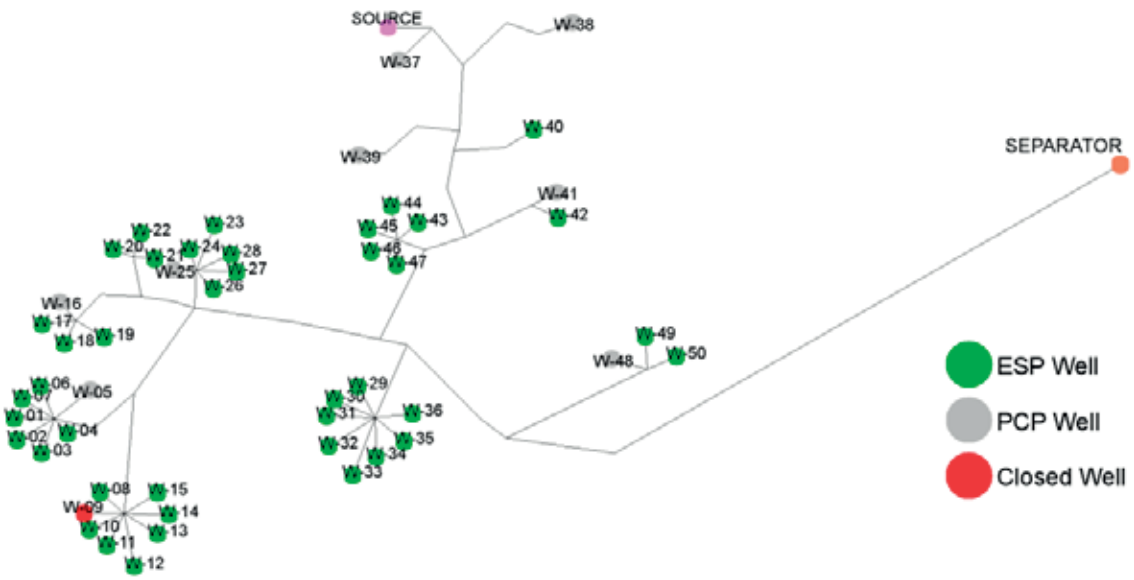
Model-based production optimization for production networks with ESP-produced, high water cut wells

The modeling and optimization of large production networks of multi-branched gathering systems (as shown in the figure) has been addressed in 2013. The numerical optimization consists on maximizing oil production by changing ESP frequency and subjected to multiple operational constraints. The methodology has yielded promising results for simplified test cases with few wells and for real field systems with multiple wells.

The research also addresses the development of models to represent the hydraulic deliverability behavior of individual horizontal wells under water coning conditions. The tools employed for the analysis are reservoir simulation and analitycal proxy model based in field data.

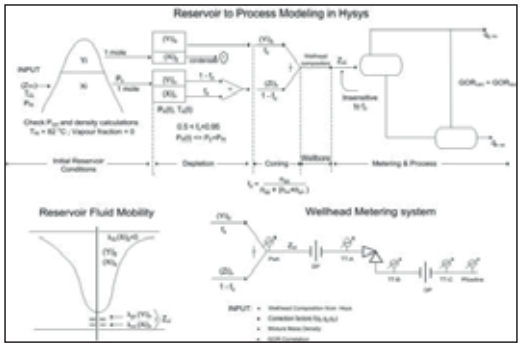
Virtual multiphase metering and production allocation

A research is conducted to develop a virtual metering scheme of oil wells producing oil, gas and water. This is to allow a continuous rate and composition calculation of each phase produced by each well without employing a dedicated multiphase flow meter. The challenge in the research is to combine pressure loss measurements in multiple surface flow restrictions, together with the associated temperature variations, and coupling the data with simulated fluid composition tracked from the reservoir to the surface facilities and standard conditions. When used in fields where a periodic well testing (monthly) are practiced, the scheme is tuned to the test data and provides a continuous and daily average production rates and molecular composition of the well stream fluids for the period between the well tests.

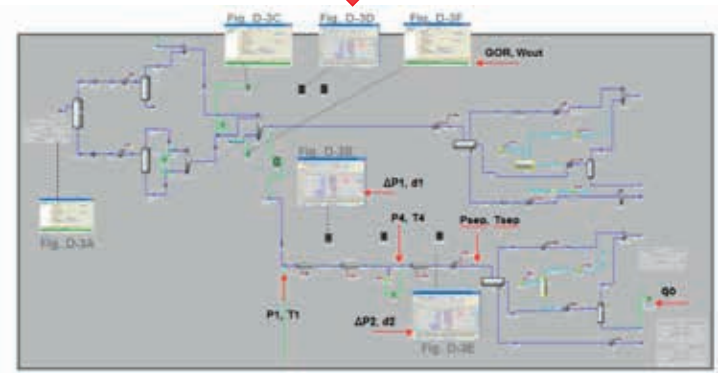


Scheme of a surface network in a hydrocarbon production system

CONCEPT



APPLICATION USING HYSYS



Virtual metering scheme implemented in HYSYS

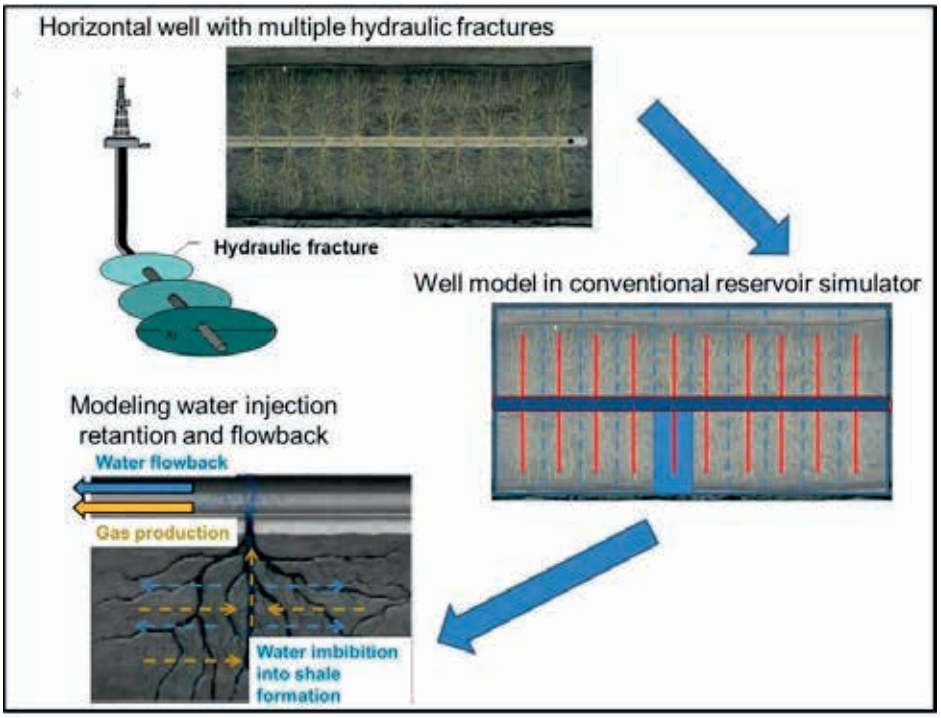
The research has also focused on developing modeling strategies to represent the thermodynamic and hydraulic expansion of well fluids in production chokes and flow restrictions.

2D streamlines depicting velocity magnitude of fluid passing through a bean choke

Modeling of water injection process and post hydraulic fracturing cleanup of shale gas wells

Research work is conducted on modeling the water injection process and post hydraulic-fracturing cleanup of shale gas wells. This is to allow determining the impact of cleanup and dewatering strategy on the short term and long term gas production performance of wells.

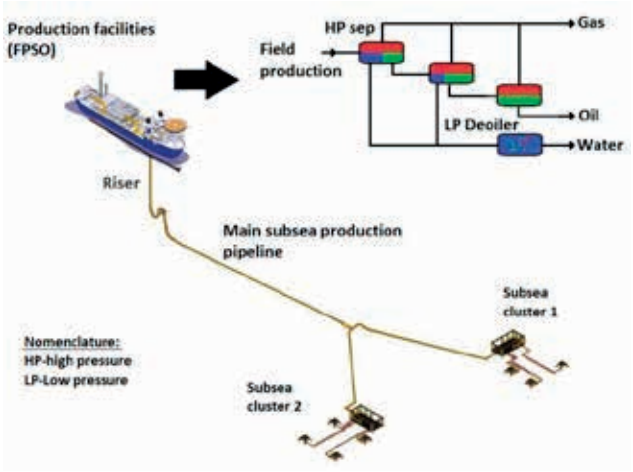
The challenge in the research is to represent the complex nano-scale physical phenomena of the liquid and gas flowing in tight shale formations, where permeability is in the range of 10-2 to 10-4 millidarcy, in practical reservoir simulator scales. Such presentation allows employing conventional reservoir simulation practices to predict the gas production performance and fracturing water recovery characteristics, and using production data to tune the simulator for predictions and forecasts.



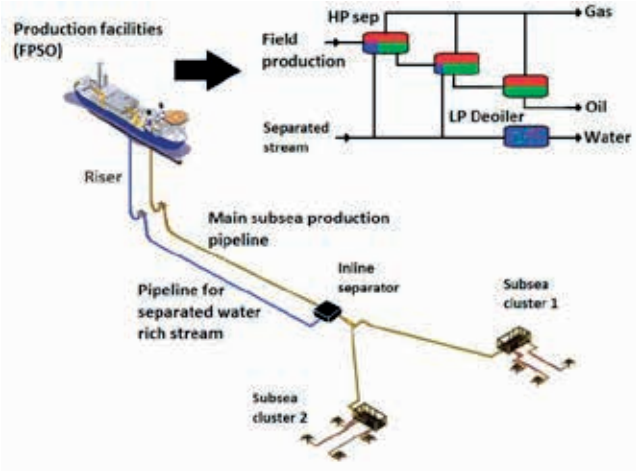
Water modeling in hydraulically fractured shale gas wells

Inline oil-water separation for subsea applications

A multi-year program investigating and modeling oil-water separation in inclined pipes with multiple tapping points has advanced further in 2013. The program started originally as a NFR Demo 2000 program and extended as a faculty research project. The research progresses the relevant previous knowledge and information from a concept validation level to establishing and validating a more detailed design strategy and a more focused performance design for the separator. The research brings the investigated separation approach to a mature level where the fluid mechanics design aspects are largely clear and understood and are ready as an input for the mechanical design of a separator prototype.



Original production system (no inline separator)



Production system with the inline separator

Doctoral thesis

Stroisz Anna Magdalena
Nonlinear Elastic Waves for Estimation of Rock Properties
Supervisor: Adjunct Professor

Barker Daniel
Close Range Interactions between Air Guns
Supervisor: Professor Martin Landrø

Ghasemi Mohammad
Optimization of Thermal Processes in Heavy Oil Recovery
Supervisor: Professor Curtis H. Whitson

Souraki Yaser
Experimental Investigation and Numerical Simulation of Thermal Recovery Processes Applicable in Athabasca Bitumen Reservoirs
Supervisor: Professor Ole Torsæter

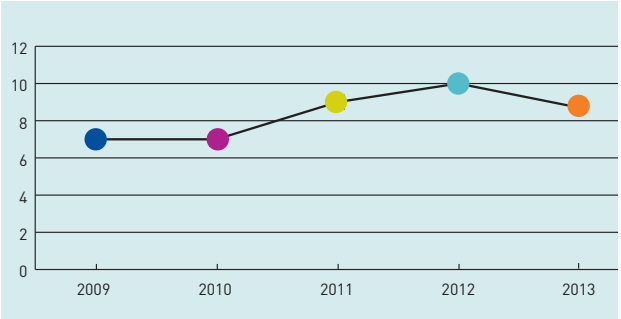
Ashrafi Mohammad
Experimental Investigation of Temperature Dependency of Relative Permeability Data in Heavy Oil Systems with Applications to Thermal Recovery
Supervisor: Professor Ole Torsæter

Wiik Torgeir
Modeling and Inversion of Marine Electromagnetic Data - with applications in hydrocarbon prospecting
Supervisor: Professor Bjørn Ursin

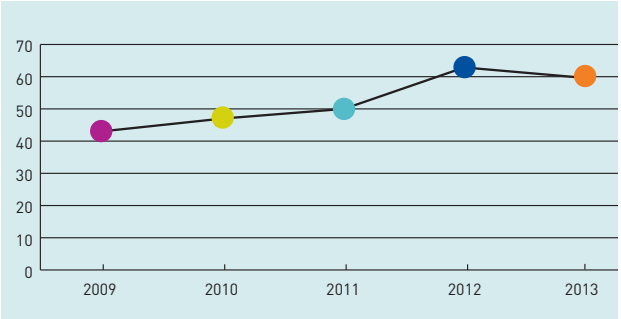
Kolstø Morten Ivar
Water in shale: Molecular modeling and Rock Physics Experiments
Supervisor: Professor Rune Martin Holt

Nasuti Aziz
Using geophysical methods to characterize the Møre-Trøndelag Fault Complex, Mid Norway
Supervisor: Adjunct Associate Professor II Jörg Ebbing

Shokouhi Samad Valipour
Real-time optimized drilling operation by using Artificial Intelligence
Supervisor: Associate Professor Pål Skalle



Number of Ph.D Graduates.



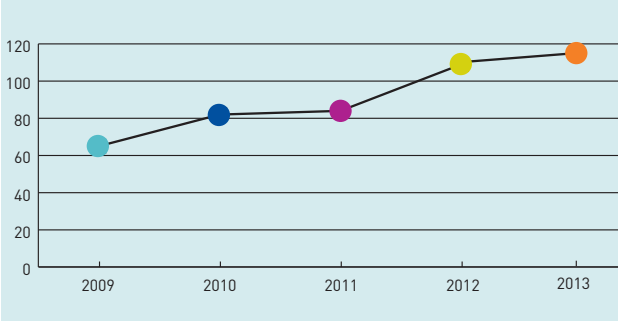
Number of Publication Points.

EDUCATION

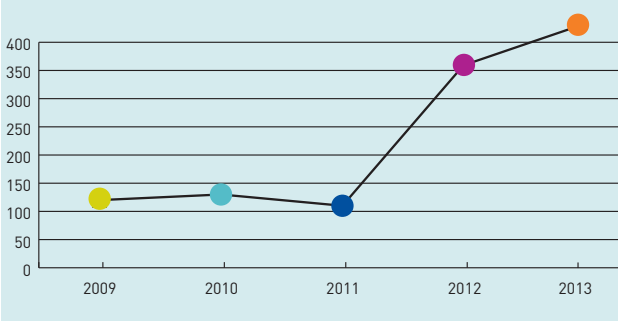
MSC COURSES		RESPONSIBLE	STUDENTS	CLASS YEAR
TPG4100	Physics and Geophysics	Martin Landrø	68	2
TPG4105	Petroleum Engineering, Basic course	Alexey Stovas	55	3
TPG4112	Geomechanics and Flow in Porous Media	Ole Torsæter	73	2
TPG4115	Reservoir Property Determination by Core Analysis and Well Testing	Ole Torsæter	53	3
TPG4117	Unconventional Oil and Gas Reservoirs	Ole Torsæter	22	4
TPG4120	Mineral, Engineering and Environmental Geophysics	Jan Steinar Rønning	39	3
TPG4125	Seismic Wave Propagation	Egil Tjåland	50	3
TPG4130	Seismic Interpretation	Egil Tjåland	49	4
TPG4135	Processing of Petroleum	Jon Steinar Gudmundsson	41	3
TPG4140	Natural Gas	Jon Steinar Gudmundsson	49	4
TPG4145	Reservoir Fluids and Flow	Curtis Hays Whitson	59	3
TPG4150	Reservoir Recovery Techniques	Jon Kleppe	60	4
TPG4151	Subsurface Decision Analysis	Reidar B. Bratvold	10	4
TPG4155	Applied Computer Methods in Petroleum Science	Børge Arntsen	53	3
TPG4160	Reservoir Simulation	Jon Kleppe	48	4
TPG4162	3D Visualization of Petroleum Data	Stein Inge Dale	11	4
TPG4165	Geophysical Analysis	Børge Arntsen	17	3
TPG4170	Reservoir Seismics	Børge Arntsen	27	4
TPG4175	Petrophysics – Well Logging, Fundamentals	Erik Skogen	105	3
TPG4177	Carbonate Reservoir Characterization	Adviser Lisbeth Hultmann	14	4
TPG4180	Petrophysics, Interpretation of Well Data, Advanced course	Rune Martin Holt	14	4
TPG4185	Formation Mechanics	Rune Martin Holt	53	3
TPG4190	Seismic Data Acquisition and Processing	Martin Landrø	20	4
TPG4200	Subsea Production Systems	Sigbjørn Sangesland	54	4
TPG4205	Drilling Techniques Pressure Control	Pål Skalle	29	4
TPG4210	Drilling Engineering	Arild Rødland	35	3
TPG4215	High Deviation Drilling	Sigbjørn Sangesland	36	4
TPG4220	Drilling Fluid	Pål Skalle	33	4
TPG4225	Fractured Reservoirs	Ole Torsæter	21	4
TPG4230	Field Development and Operations	Michael Golan	34	4
TPG4235	Well Testing, Advanced Course	Tom Aage Jelmert	3	4
TPG4245	Production Wells	Harald Arne Asheim	22	4
TPG4250	Electromagnetic Methods in Oil Exploration	Ståle Emil Johansen	11	4
TPG4255	CO2 Storage: Operation and Integrity of Engineered CO2 Storage	Philip Ringrose	18	4
TPG4510	Petroleum Production, Specialization Project	Harald Arne Asheim	7	5
TPG4515	Petroleum Production, Specialization Course	Harald Arne Asheim	5	5
TPG4520	Drilling Engineering, Specialization Project	Pål Skalle	40	5
TPG4525	Drilling Engineering, Specialization Course	Pål Skalle	25	5
TPG4530	Reservoir Engineering and Petrophysics, Specialization Project	Jon Kleppe	31	5

MSC COURSES		RESPONSIBLE	STUDENTS	CLASS YEAR
TPG4535	Reservoir Engineering and Petrophysics, Specialization Course	Jon Kleppe	32	5
TPG4540	Petroleum Geophysics,Specialization Project	Egil Tjåland	22	5
TPG4545	Petroleum Geophysics,Specialization Course	Egil Tjåland	13	5
TPG4550	Integrated Operations in the Petroleum Industry, Specialization Project	Egil Tjåland	2	5
TPG4555	Integrated Operations in the Petroleum Industry, Specialization Course	Egil Tjåland	1	5
TPG4850	Experts in Teamwork – VR Village	Egil Tjåland	29	4
TPG4851	Experts in Teamwork – Gullfaks Village	Jon Kleppe	36	4
TPG4852	Experts in Teamwork – Norne Village	Richard Wilfred Rwechungura	31	4
TPG4905	Petroleum Engineering - Petroleum Production, Master's Thesis	Several	8	5
TPG4910	Petroleum Engineering - Drilling Engineering, Master's Thesis	Several	31	5
TPG4915	Petroleum Engineering - Reservoir Engineering and Petrophysics, Master's Thesis	Several	11	5
TPG4920	Petroleum Engineering, Master's Thesis	Several	23	5
TPG4925	Petroleum Geosciences, Master's Thesis	Jon Kleppe	11	5
TPG4930	Applied Petroleum Geophysics, Master's Thesis	Several	19	5
TPG4935	Integrated Operations in the Petroleum Industry, Master's Thesis	Several	1	5
TPG5100	Applied Mathematics and Computer Methods in Petroleum	Børge Arntsen	37	4
TPG5110	Petroleum Economics	Trygve Strøm	82	4
TPG5130	Seismic Processing	Egil Tjåland	3	4
TPG5140	Specialization in Sub Surface Management	Michael Golan	4	4

PHD COURSES		RESPONSIBLE	STUDENTS
PG8106	Mathematical Geophysics	Lasse Amundsen	2
PG8108	Elecromagnetic and Seismic Inverse Methods	Ketil Hokstad	4
PG8202	Interpretation of Combined Geophysics. Application of Gravimetry and Magnetometry in Geological Models	Jörg Ebbing	1
PG8300	Rock Physics	Rune Martin Holt	4
PG8401	Well Mechanics and Completion	Michael Golan	1
PG8403	Modelling and Simulation of Produciton Processes	Michael Golan	2
PG8500	Experience Transfer in Drilling Engineering	Pål Skalle	2
PG8600	Development of Numerical Reservoir Models	Jon Kleppe	1
PG8603	Advanced Phase Behavior for Petroleum Reservoir Fluids	Curtis Hays Whitson	1
PG8606	Gas Engineering – Reservoir and Production	Curtis Hays Whitson	1
PG8607	Numerical Methods in Reservoir Simulation	Odd Steve Hustad	3



Number of M.Sc. Graduates.



Number of Primary Applicants (First Choice Applicants) to Petroleum Studies.

Thesis – graduate studies

Petroleum Geoscience and Engineering (5 years)

Aarnes, Andreas Røysland
AVO Analysis of Subglacial Forms in the North Sea, with the use of High Resolution 3D Seismic
Supervisor: Landrø, Martin

Aftret, Brage Vikaune
Seismic Characterization of the Ty Member Sandstones, Block 25/8,
Norwegian North Sea
Supervisor: Landrø, Martin

Alipour, Samaneh
Numerical Modeling and History Matching of Super-Wet Combustion Tube Test
Supervisor: Torsæter, Ole

Anthonsen, Bjørn Sirevaag
Material Balance applied to an
actual field case
Supervisor: Kleppe, Jon

Aschjem, Gunnar
Mapping Reservoir Changes Using 4D Seismic on the Norne G-segment, Norwegian Sea
Supervisor: Landrø, Martin

Austrheim, Eli Kristine Sook
Forward Seismic Modelling of Volcanic Intrusions from Independence
Fjord - Northeast Greenland
Supervisor: Johansen, Ståle Emil

Basarab, Nataliya
Modeling of gel deformation
Supervisor: Skalle, Pål

Benavides, Sebastian Osvaldo Zuniga
Separation Technologies in Oil and Gas Production
Supervisor: Gudmundsson, Jon Steinar

Birkeland, Marthe Åsnes
Investigation of Nanoparticle Effect on Wettability and Interfacial tension
Supervisor: Torsæter, Ole

Bjerke, Hanne
Revealing Causes of Restrictions by Signatures in Real-Time Hook Load Signals
Supervisor: Skalle, Pål

Bjørnseth, Fabian
Heavy Oil Production Technology Challenges and the Effect of Nano Sized Metals on the Viscosity of Heavy Oil
Supervisor: Gudmundsson, Jon Steinar

Boge, Andreas Laupstad
MPD Heave Lab
Supervisor: Godhavn, John-Morten

Dahle, Jørgen Eikenes
Simulation of Coalbed Methane production in Eclipse 100 and Tempest MORE
Supervisor: Kleppe, Jon

Dennis, Francis Ato
Prospect Analysis of Mumbai High, India
Supervisor: Tjåland, Egil

Eide, Maren Vebenstad
P-cube and AVO Analysis of Skrugard and Havis
Supervisor: Tjåland, Egil

Ekerheim, Stian Bessesen
Regional geological seismic interpretation of Triassic infill in the southwestern Barents Sea
Supervisor: Johansen, Ståle Emil

Ekseth, Astrid Fosså
Modelling of Surface Hook Load Signals when Tripping Out of Hole
Supervisor: Skalle, Pål

Engås, Aleksander
Forward Seismic Modeling: A Case Study from the Froan Basin and the Frøya High Area
Supervisor: Johansen, Ståle Emil

Espe, Tori
A seismic and facies interpretation of the Late Paleozoic Carbonates of the South Eastern Barents Sea in Norway and Russia
Supervisor: Johansen, Ståle Emil

Evensen, Kristoffer
Surface Seismic While Drilling
Supervisor: Sangesland, Sigbjørn

Fiskkjønli, Eirik
Analysis of methods for effective well plug and abandonment (P&A)
Supervisor: Sangesland, Sigbjørn

Flo, Per Inge Bjørkedal
Seismic Study of the Outer Vøring Margin
Supervisor: Johansen, Ståle Emil

Frafjord, Christine
Friction Factor Model and Interpretation of Real Time Data
Supervisor: Skalle, Pål

Fredriksen, Ida
Rock Physics Properties and Seismic Signatures of Hot Shales on the Norwegian Shelf
Supervisor: Avseth, Per Åge

Gjengedal, Carolin
Pipeline Pressure Drop in Heavy Oil Production
Supervisor: Gudmundsson, Jon Steinar

Gundersen, Anders
Evaluation of Methods for Drilling and Production of Hydrate Formations
Supervisor: Sangesland, Sigbjørn

Haavik, Kjetil Eik
Deghosting of Marine Seismic Data Using Dual Sensor Technology
Supervisor: Landrø, Martin

Haga, Arild
An Evaluation of Casing Concept for Maximum Final Diameter for Geothermal Well SCH2, KH1, in Krupina, Slovakia
Supervisor: Rødland, Arild

Hansen, Jørn-Åge
Drilling program for Middle-European Volcanoclastic rock
Supervisor: Rødland, Arild

Hanssen, Alexander Rikstad
Numerical modelling of Bingham fluid flow and particle transport in a rough-walled fracture
Supervisor: Holt, Rune Martin

Hiller, Oda Normann
An Investigation of Fault Displacement and Polarity in the northern North Sea
Supervisor: Tjåland, Egil

Holme, Asbjørn
Optimization of Liquid-Rich Shale Wells
Supervisor: Whitson, Curtis Hays

Jakobsen, Fredrik G
Estimation of Seismic Parameters by Source Strength Variation
Supervisor: Landrø, Martin

Jonassen, Anette Hartveit
Distribution of Hydrate Inhibitors in Processing of Gas-Condensate
Supervisor: Gudmundsson, Jon Steinar

Jørgensen, Kristian
Implementation of a Surfactant Model in MRST With Basis in Schlumberger's Eclipse
Supervisor: Torsæter, Ole

Kaasa, Anne Tinnen
Investigation of how Silica Nanoparticle Adsorption Affects Wettability in Water-Wet Berea Sandstone
Supervisor: Torsæter, Ole

Kallhovd, Anders
Evaluation of a dual relief well operation
Supervisor: Sangesland, Sigbjørn

Killerud, Marie
Comparison of Dry Gas Seasonal Storage with CO_2 Storage and Re-Use Potential
Supervisor: Ringrose, Philip

Kjellevoll, Ingrid Solberg
Casing Wear
Supervisor: Sangesland, Sigbjørn

Kjøraas, Margaret
Structure of Paraffin Wax Deposits in Subsea Pipelines
Supervisor: Gudmundsson, Jon Steinar

Kristensen, Aleksander
Flow properties of water-based drilling fluids
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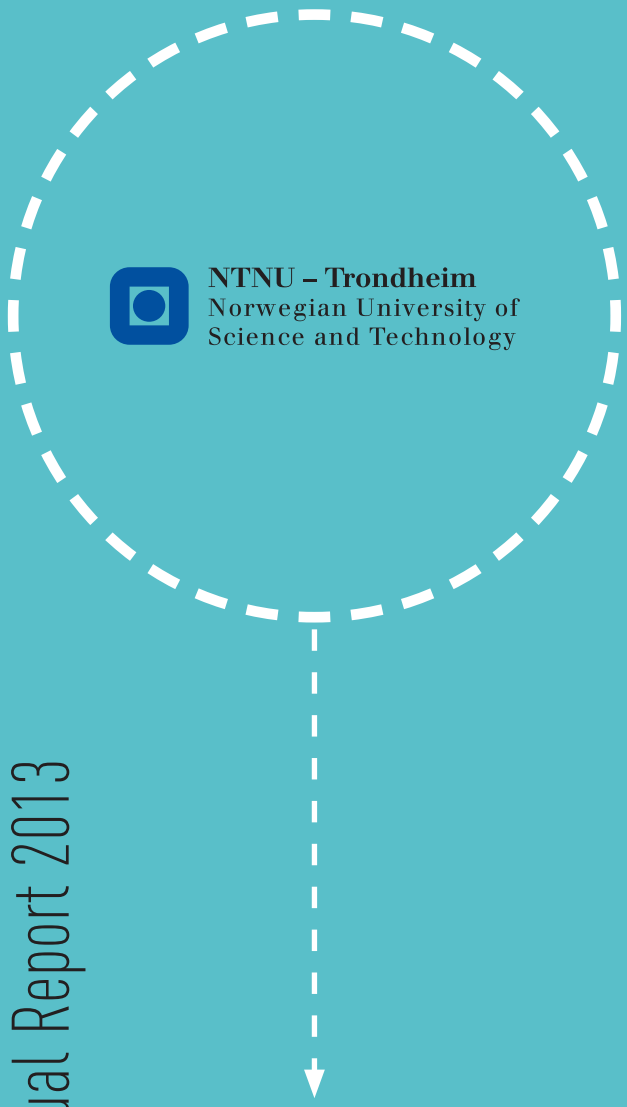

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