ANNUAL REPORT 2015

The National IOR Centre of Norway

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UNTOUCHED SNOW COVERED EXPANSE, TRACKS ARE SLOWLY GROWING.

RESOLUTE STEPS OF CARIBOU LEADER, DISTANT SHIMMERING GOAL.

RELYING ON EACH OTHER, COOPERATION STRENGTHENS AND GROWS.

EXPLORING AN UNKNOWN LANDSCAPE, A LANDSCAPE SOON TO BE KNOWN.

WE THANK YOU FOR THE PREVIOUS YEAR, THE CHALLENGES, JOY OF SUCCESS.

THE IOR CENTRE STRENGTH, THE SYNERGY FROM COOPERATION ACROSS.

THE NEW YEAR SHINES BEFORE US, ATTRACTS US, ONWARD, ONWARD..

JAN SAGEN, IFE
TRANSLATED BY TERESA PALMER, IFE

THE PARTNERS

University of Stavanger
IRIS
IFE
ENGIE
MAERSK OIL
wintershall
eni norge
DONG energy
HALLIBURTON
Schlumberger
ConocoPhillips
Lundin Norway
Statoil
bp
DETNORSKE

OBSERVERS

The Research Council of Norway
NORWEGIAN PETROLEUM DIRECTORATE
petoro

THE MANAGEMENT

Merete V. Madland
Centre Director

Kristin M. Flornes
Assistant Director

Aksel Hiorth
Director of Research

Svein M. Skjæveland
Director of Academia

Randi Valestrand
Director of Research

Sissel Opsahl Viig
Director of Field Implementation

THE BOARD

Kåre Vagle, ConocoPhillips (Chair)
Randi Elisabeth Hugdahl, Statoil
Roar Kjelstadli, BP
Mailin Seldal, ENGIE E&P NORGE AS
Yngve Brynjulfsen, Eni Norge
Tore Bjerklund Gimse, IFE
Ole Ringdal, IRIS
Øystein Lund Bø, UiS

Deputy candidates: Ole Eeg (ConocoPhillips), Kevin Webb (BP),
Nora Hveding Bergseth (ENI) Sigbjørn Kalvenes (ENGIE E&P NORGE AS) Bjørn Hjertager (UiS),
Torkell Gjerstad (IRIS), Johan Kristian Sveen (IFE), Øivind Fevang (Statoil)

Observers:
Ingrid Anne Munz, Research Council of Norway
Mariann Dalland, Norwegian Petroleum Directorate
Erik Søndenå, Petoro

TECHNICAL COMMITTEE

Consists of representatives from each user partner

Chair: Steinar Kristiansen (Wintershall Norge)
Andrea Reinholdtsen (ENGIE E&P NORGE AS), Bjørn Gulbrandsen (Lundin), Trygve Nilsson (Det norske oljeselskap), Robert Moe (ConocoPhillips), Amare Mebratu (Halliburton), Kevin Webb (BP), Lars Sønneland (Schlumberger), Siroos Salimi (ENI Norge AS), Niels Lindeloff (Maersk Oil Norway AS), Knut Uleberg (Statoil), Eirik Jensen (DONG)

Deputy candidates: Mailin Seldal (ENGIE E&P NORGE AS), Olav Flornes (Lundin), Kåre Langaas (Det norske oljeselskap), Edvard Omdal (ConocoPhillips), Saeed Fallah (Wintershall Norge), Ingrid Melien (Halliburton), Roar Kjeldstadli (BP), Jarle Haukås (Schlumberger), Knut Ingvar Nilsen (ENI Norge AS), Kristin Ingnes (Maersk Oil Norway AS), Alf Birger Rustad (Statoil), Gustav Kvaal (DONG)

ORGANISATION

Photo: General assembly 2015. The General Assembly, organized yearly, is the ultimate decision making body of the project, and will elect The Centre Board.

Photo: Several meetings are organized each year, in order to keep a close cooperation with the user partners. Picture from the site-visit when the Research Council of Norway visited UiS in 2015.

The National IOR Centre of Norway:

- Consortium of 15 partners. Three research partners: University of Stavanger (UiS), International Research Institute of Stavanger (IRIS) and Institute for Energy Technology (IFE) and 12 user partners: ConocoPhillips Skandinavia AS, BP Norge AS, Det Norske Oljeselskap AS, Eni Norge AS, Maersk Oil Norway AS, DONG Energy A/S, Denmark, Statoil Petroleum AS, ENGIE E&P NORGE AS, Lundin Norway AS, Halliburton AS, Schlumberger Norge AS, Wintershall Norge AS
- Vision: Joining forces to recover more
- Awarded by the Research Council of Norway, with start-up in 2013
- Centre director: Merete Vadla Madland: In charge of the overall progress and performance of The Centre
- The Management Team: Director Merete Vadla Madland, Assistant Director Kristin Flornes, Research Directors Aksel Hiorth and Randi Valestrand, Director of Adacemia Svein Skjæveland and Director of Field Implementation Sissel Opsahl Viig
- Host institution: University of Stavanger
- The board: Representatives from research and user partners - the majority is held by the user partners
- Annual budget 2015: ~58 000KNOK

THE THEMES

The research is organised in two R&D themes with seven main Tasks, which are specified by a research plan covering deliverables, milestones and methodology. Researchers from UiS, IRIS, and IFE serve as task leaders. As an overall strategy in these tasks, we will involve researchers coming from different research environments (IOR/EOR, reservoir, chemistry, geology, geochemistry, geophysics, mathematics, nano- science/ technology, biochemistry, environmental, industrial economy) from the partners as well as national and international collaborators. Efficient and good working routines have been established.

Tasks and theme leaders meet bi-weekly and the task leaders participate in regular project meetings with the project leaders. This ensures a steady flow of information between the participants of The Centre.

In 2015, Randi Valestrand from IRIS took over for Geir Nævdal as leader of Theme 2. Geir Nævdal is still leader of Task 7, and works actively in The Centre.

Robert Klöfkorn (IRIS) was chosen as the new leader for Task 6, after Steinar Evje (UiS) decided to step down in order to focus more on his research. Steinar Evje is still active in The Centre as project manager and supervisor.

THE MANAGEMENT TEAM

The Management Team has weekly meetings in order to co-ordinate the ongoing research activities and discuss current topics. This ensures a good collaboration between all the research partners.

BOARD AND TECHNICAL COMMITTEE

Three board meetings were held in 2015. In connection with these meetings a total of four meetings in the technical committee (TC) were held. The TC is the technical advisory body to the Board, consisting of representatives from each of the 12 user partners. In addition to the board and technical committee meetings, the General Assembly was held in October 2015. Election of new Board was not scheduled for 2015, and Kåre Vagle from ConocoPhillips has been serving as chairman in 2015.

COLLABORATION

We aim for an open Centre structure. Cooperation and openness are keywords for The Centre, and we strive to maintain a good contact with our collaborators. Through an active collaboration, we aim to promote applicable research of a high scientific level.

Photo: PhD candidate Mona W. Minde is explaining her work to Reidar Inge Korsnes (UiS), Arne Holhjem and Mariann Dalland, both from the Norwegian Petroleum Directorate.

UNIVERSITY OF BERGEN:

• Key contacts: Professor Arne Graue, Associate Professor Martin Fernø at the Institute of Physics and Technology, Professor Morten Jakobsen at the Department of Earth Science, University of Bergen

• Centre PhD student: PhD Mohan Sharma: "Displacement mechanisms in heterogeneous reservoirs with CO_2 foam for mobility control; upscaling for field applications"

• Researcher Dr. Bergit Brattekås: "Integrated EOR for heterogeneous reservoirs"

• Professor Morten Jakobsen has a 20 per cent position at IRIS under The National IOR Centre to increase The Centre's expertise in geophysics. This is especially important for activities that deal with the use of 4D seismic data in reservoir characterization and assisted history matching (data assimilation). An IRIS team working with 4D data has weekly meetings with Professor Morten Jakobsen, where research results and research initiatives are discussed and key references are given.

UNIVERSITY OF OSLO:

• Key contacts: Professor Dag Dysthe, Dr. Anja Røyne, Professor Anders Malthe-Sørenssen, external PhD (UiO) Sigve Skattum

• Centre PhD student: Shaghayegh Javadi: "Experimental investigation of the effect of fluid chemistry on the adhesive properties of calcite grains"

NTNU / UGELSTAD LABORATORY:

• Key contacts: Professor Johan Sjøblom, chief engineer Camilla Dagsgård

• Various project cooperations / meetings / seminars and workshops

SINTEF:

• Key contacts: Professor Knut Andreas Lie, Dr. Xavier Raynaud

• IRIS collaborates in the development of open source reservoir simulation tools. Within The Centre work is done to develop better physical, mathematical and numerical methods for EOR. A postdoc at IRIS is working close with SINTEF on numerical methods for improving simulation of polymer flooding.

INTERNATIONAL COOPERATION:

In addition to active cooperation with Netherlands Organization for Applied Scientific Research (TNO), Delft University of Technology (TU Delft) in the Netherlands, Cornell University, University of Texas at Austin (UT Austin) and the National Center for Atmospheric Research (NCAR) USA, Technical University of Denmark (DTU), Copenhagen University, GEO and Geus in Denmark, University of Lyon in France and Institute for the Study of the Earth's Interior (ISEI); Centre of Excellence in Japan, Sandia National Laboratories, more contacts are added consecutively.

There has been good mobility in 2015 to TNO and TU Delft and one of the fellows has been at Copenhagen University for a shorter stay.

DTU / GEO / GEUS:

• Key contacts: Professor Ida Lykke Fabricius, Chief Engineer Helle Foged Christensen and Dr. Claus Kjøller

•Centre PhD: Tijana Livada

Professor Fabricius is employed as Professor II at the University of Stavanger and is supervisor for one of The Centre's PhD students and several MSc students at the University of Stavanger.

UNIVERSITY OF ABERDEEN:

• Key contact: Professor Alex Kemp - Economic analyses of IOR-projects

TNO:

• Key contacts: Dr. Olwijn Leeuwenburgh, Dr. Philippe Steeghs, PhD student Rahul Fonseca (TU Delft / TNO)

• Centre Postdoc: Yanhui Zhang

• TNO has a postdoc from The National IOR Centre. The postdoc's work is on data assimilation using 4D seismic data. The work will also be supervised by researchers at TNO, such as Olwijn Leeuwenburgh and Dr.Philippe Steeghs. An IRIS research team is working with 4D data, conduct several meetings with the TNO postdoc and his supervisors Dr. Philippe Steeghs is project manager at TNO in all activities concerning the IOR Centre. The Centre also collaborates with TNO in production optimization.

TU DELFT:

• Key contacts: Professor Jan Dirk Jansen (TU Delft), PhD student Rahul Fonseca (TU Delft / TNO)

• Professor Jan Dirk Jansen is head of the department of Geoscience & Engineering and professor of Reservoir Systems and Control at the University TU Delft. IRIS has a good research collaboration with TU Delft in production optimization. Senior researcher Dr. Andreas Stordal has been invited by Professor Jan Dirk Jansen to a 6 week stay at TU Delft as a visiting lecturer each year. The collaboration will strengthen the research and make The Centre more international.

Photo: UiS and IRIS have a long lasting relationship with professor Lawrence M Cathles from Cornell University.

CORNELL UNIVERSITY:
• Key contacts: Professor Lawrence M. Cathles
• IFE has a partnership with Lawrence M. Cathles at Cornell University on the use of C-dots as tracers in porous media. C-dots are nanoparticles developed at Cornell University. IFE's job is to determine the size of the particles and defining the limit of detection for these, in addition to implementing dynamic experiments to look at the particles flooding characteristics.

UNIVERSITY OF TEXAS AT AUSTIN (UT AUSTIN):
• Key contacts: Professor Larry Lake
• Project Collaboration: Robust Production Optimization. In this collaboration, the focus is on the use of less detailed models (CRM - Capacitance Resistance Model) for reservoir simulation for use in connection optimization. One of The IOR Centre's PhD students and professors are involved, and both are planning to spend a semester at UT in 2016/17.

INSTITUTE FOR THE STUDY OF THE EARTH`S INTERIOR (ISEI):
• Key contacts: Professor Eizo Nakamura
• Project: quantification of chemical changes in flooded chalk on homogenized and natural samples with Field-Emission - Transmission Electron Microscope
• Research Assistant: MSc. Nina Egeland, planned research stay in the period January-June 2016

UNIVERSITÉ DE LYON:
• Key contacts: Professor Olivier Tillement
• IFE cooperates with Olivier Tillement at Université de Lyon. The collaboration involves the characterization of the different characteristics of nanoparticles and complexes. These are components being tested as possible new tracers to determine the oil saturation in a flooded area of a reservoir.

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH (NCAR):
Key executives: Dr. Dorit Hammerling and Dr. Ram Nair.
Dr. Robert Klöfkorn has been on a 3-month research stay at the Computational and Information Systems Laboratory (CISL) of the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. NCAR's Computing Lab are specialists in mathematical and statistical methods to simulate and predict complex stochastic phenomena. This is a very useful cooperation for The IOR Centre in terms of simulation of IOR and EOR methods in reservoir.

SANDIA NATIONAL LABORATORIES:
• Three-dimensional imaging and pore-scale modelling of carbonate rocks
• Key contact: Dr. Hongkyu Yoon

HELMHOLTZ INSTITUTE FREIBERG FOR RESOURCE TECHNOLOGY AT DRESDEN WITH TU BERGAKADEMIE FREIBERG:
• Key contact: Professor Bernhard Schultze, professor Jens Gutzmer and professor Razvigor Ossikovski

INSTITUTE OF SCIENCE AND TECHNOLOGY IN LUXEMBOURG:
• Key contact: Dr. Jean Nicolas Audinot

UNIVERSITY OF MÜNSTER GERMANY
• Key contact: Dr. Christian Vollmer

UNIVERSITY OF EDINBURGH:
• Key contact: Dr. Colin Chilcott

UNIVERSITY OF HOUSTON:
• Key contact: Dr.Thomas Lapen

UNIVERSITÁ BIOCCA MILANO:
• Key contact: Dr. Sergio Andó

Photo: Visiting Helle Foged Christensen, chief engineer at GEO in Denmark. One of the many international research collaborators in The National IOR Centre of Norway.

Photo: Professor Jan Dirk Jansen, TU Delft, is a very valued collaborator to The Centre.

Photo: Professor Eizo Nakamura from Institute for the Study of the Earth's Interior, Japan. Here at the official opening of The National IOR Centre of Norway.

THE DIRECTOR'S VIEW

The world needs energy, and more than 50% of the petroleum resources are left in the ground on the Norwegian Continental Shelf. We have a responsibility to improve the recovery, whilst reducing costs and mitigating environmental impact. To achieve this goal, it is important that all stake holders work together, and The National IOR Centre is an important arena for doing exactly that.

During 2015 we have worked even harder; building a true national research team. Together we aim to improve science and engineering, learning from good practice in service and oil companies, and finally yet importantly sharing our knowledge and ideas, thus forming a platform for unique IOR competence in Norway. The Centre's slogan joining forces to recover more was as such a natural choice as discussing the topic for our first annual IOR conference; IOR NORWAY 2015. The two days conference along with a one day workshop did gather more than 300 researchers as well as experts from the oil – and service companies. The three research partners together with some of the 12 user partners presented their work in addition to invited speakers from all around the world.

During autumn 2015 the establishment of a research road map has shown to become a useful tool in prioritizing the Centre's R&D projects and ensuring a steady flow of communication across the research themes as well as amongst the individual researchers and industry experts. The outcome of the R&D activities so far, reflects the unique co-operations achieved within The Centre; not only between the three research partners, however, this also includes the many national and international collaborators, active interactions between the two research themes, the tasks and projects, in addition to the strong involvement from the supporting companies. Finally, I would like to list some of the many highlights in 2015:

- 13 PhDs were recruited the last year and the total number of PhDs and Post docs are now 16 and 8, respectively.
- The large-scale polymer degradation test led by Halliburton and the development of our simulation tool, IORSim, in which Schlumberger supports in getting to communicate efficiently with the commercial reservoir simulator Eclipse.
- The release of relevant and specific field data which helps calibrating our models.
- Development of an open source reservoir simulator (OPM), which allows for easy collaboration between research institutes and industry partners, has resulted in three software releases. Moreover also a spin-off project with the industry has been granted and will strengthen the OPM development even further.
- At IFE development of new more environmentally friendly tracers, which can be detected at very low concentrations, are progressing.
- Developing and testing of methodologies for including the information from 4D seismic data in history matching using ensemble based methods. This approach shows to be promising on synthetic cases and we are working to bring the methodology further to be applicable on real field cases.

Professor Merete Vadla Madland
Centre Director

MESSAGE FROM THE CHAIRMAN

The main focus at National IOR Centre during 2015 have been directed towards consolidating center management processes, research activity and ensure continuation of performance at a high scientific level.

The Technical Committee has become an arena for good dialogue and cooperation between User and Research partners. A result of common effort was construction of a Road Map, which has been instrumental in defining key activities and milestones that are required to meet the objective of demonstrating potential for increased recovery, through mobilization of immobile oil and improved volumetric sweep, in fields on the Norwegian Continental Shelf.

The first annual IOR conference held at the University of Stavanger in April with a good mix of international, national and internal speakers and 300 attendees, contributed in building center identity and status.

The number of researchers has continued to grow with 16 PhDs and 8 Post Docs fully engaged in center activities and contributing in building the national knowledge base. Access to sufficient field data will continue to be critical in obtaining key deliverables needed to support materialization of field pilots. Finally, cost efficient and practical solutions must be favored over theoretical academic approaches going forward.

Kåre R. Vagle, ConocoPhillips
Chairman of the Board

THE CENTRE'S

MANAGEMENT

MERETE VADLA MADLAND
DIRECTOR

Merete Vadla Madland is professor at University of Stavanger within reservoir technology, and in autumn 2013 she became director of the new national research centre for improved recovery of petroleum resources on the Norwegian Continental Shelf. She has a PhD within geomechanics from the University of Stavanger. The last 17 years she has worked on how to most effectively extract oil from reservoir rocks. She has been heading several Research Council of Norway funded projects and numerous industry funded projects. The research has focused on understanding the physical and chemical interactions between rocks and fluids on the pore -and core (nano/micro) scale and how these can be transferred to the field (macro) scale. The work has led to SR Bank's Innovation Award in 2010, the Norwegian Petroleum Directorate's IOR prize in 2010 as part of the COREC team and Lyse`s Research Award in 2013. Madland has more than 40 publications in per reviewed journals, 70 international conference papers. She has been invited speaker and held several keynote presentations at national and international conferences/ symposiums.

KRISTIN FLORNES
ASSISTANT DIRECTOR

Kristin M. Flornes is Senior Vice President at IRIS and head of the Energy Department. She has been the vice director of The National IOR Centre of Norway since the start. Flornes holds a PhD in mathematics from Norwegian University of Science and Technology, NTNU. She has worked in the oil and energy business since 1998 and held various senior and management positions in Schlumberger, Point Carbon and since 2005 in IRIS. Her research includes work within reservoir management, assisted history matching, reservoir simulation and CO2 storage. Flornes is a board member of COREC, Centre for Oil Recovery and has been member of the programme board of CLIMIT, Norway's national programme for research, development and demonstration of CO2 capture and storage technology.

AKSEL HIORTH
DIRECTOR OF RESEARCH: THEME 1

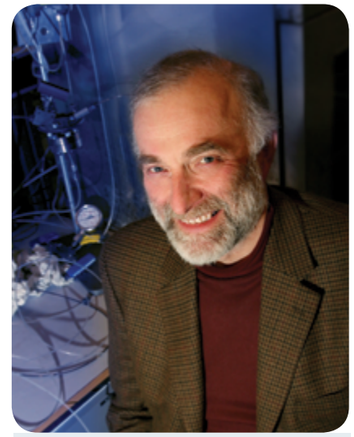
Aksel Hiorth is Chief research scientist within enhanced oil recovery (EOR) at IRIS and professor within reservoir technology at the University of Stavanger. Currently he is research director at The National IOR Centre of Norway. He has a PhD within theoretical physics from University of Oslo, and has been principal investigator within several large research projects supported by the industry and the Research Council of Norway. In the last decade he has mainly worked with developing simulation models that can describe the physical and chemical processes taking place during multiphase flow in porous rocks. He has more than 40 publications in peer reviewed journals and 20 presentations at international conferences.

RANDI VALESTRAND
DIRECTOR OF RESEARCH: THEME 2

Randi Valestrand is the Research Director at IRIS heading the Reservoir group located in Bergen. Valestrand holds a PhD degree in physics from University of Bergen. Since 1999 she has worked with research within the petroleum sector with main focus on parameter estimation, history matching, reservoir characterization and data assimilation. She has worked in IRIS since 2002 and has frequently been used as project leader for large projects sponsored by the industry and the Research Council of Norway.

SISSEL OPSAHL VIIG
DIRECTOR OF FIELD IMPLEMENTATION

Sissel Opsahl Viig is holding a position as a senior scientist with the Petroleum Technology Division at Institute for Energy Technology (IFE). She has a master degree in nuclear chemistry from the University of Oslo. She has more than ten years of experience in tracer technology and works with development of tracer methods for reservoir evaluation (interwell studies), tracer methods for determination of residual oil saturation, and analytical chemistry.



SVEIN M. SKJÆVELAND
DIRECTOR OF ACADEMIA

Svein M. Skjæveland is a reservoir engineering professor at the University of Stavanger (UiS) with a PhD from the Norwegian University of Science and Technology in engineering physics and a PhD in petroleum engineering from Texas A&M University. At UiS (Rogaland Regional College) he worked to establish the master and PhD programs in petroleum engineering and geoscience and to develop the research organization IRIS (Rogaland Research). He is an appointed "Oil Man of the Year", and has won many prizes. During 1992-94 he was an elected rector and has held many adminstrative positions in academia. He enjoys teaching and has published many papers in the fields of physics, reservoir engineering, and multiphase flow in porous media.

ROAD MAP

During 2015 a lot of effort was put into the making of the road map: A tool to help ensure progress in the research. The road map is dynamic, and will be changed accordingly, as the research progresses. The road map is to be used by all the parties in The Centre, and shows the way towards several milestones and goals. All task leaders and project leaders are expected to report on how the projects contribute towards the road map.

The overall objective of The National IOR Centre of Norway is to mobilize immobile oil and improve the volumetric sweep on fields on the Norwegian Continental Shelf (NCS). The road map of The Centre identifies a set of key activities and milestones that are required to contribute to full field IOR pilot studies.

The road map was constructed in 2015, after request from the chairman of the board. The road map was presented to all researchers of The Centre at the Hjelmeland strategy seminar, September 2015.

The road map is an important tool in order to fully evaluate new ideas and project proposals within the time frames. The map will as such visualize any gaps and be of help choosing the R&D projects.

The main goal for The National IOR Centre is to contribute to increased recovery from the NCS and the road map should be the guide telling us what we need to achieve the goal. As an example; To increase recovery, we need to prove that the method actually work with a field test, to get to a field test we need to have a business case, to have a business case we need to show that the concept has sufficient potential (including upscaling and full field simulation) and a reasonable chance of success (cost, benefit versus risk) to demonstrate the potential we need to run mechanistic laboratory work proves the concept at core and micro scale. To get to the chosen concepts we need to screen several methods/ideas to ensure that the resources are spent in the right way.

RESEARCH AND ACHIEVEMENTS IN THEME 1:

MOBILE AND IMMOBILE OIL AND EOR METHODS

Theme 1 focuses on understanding, modeling, and upscaling the microscopic and macroscopic displacement efficiency when various EOR fluids are injected into a porous rock.

We put equal emphasis on Enhanced Oil Recovery (EOR) operations in chalk and sandstone formations. The environmental impact of the EOR methods will be assessed throughout the run of The Centre.

PRIMARY OBJECTIVE OF THEME 1:

Optimize the microscopic and macroscopic displacement efficiency in a porous rock from the chemical and mineral compositions of pore fluids and rock grains, considering the sustained diagenesis and translate this knowledge to industry applications.

Secondary objectives of Theme 1:

- Develop methods of upscaling pore and core oil re covery to field scale
- Develop methods that can predict transport of chemical compounds from core to field
- A fundamental understanding of wettability and its role in porous media flow from pore-, to core and field scale
- An understanding of the impact and long term effect of EOR technologies on the reservoir
- Evaluate the environmental impact of the EOR methods.

There are several well-studied chemical injection technologies applicable for the fields on the Norwegian Continental Shelf. Thorough laboratory- and modeling studies have been performed, but there are still research challenges.

Field or pilot tests have been rare due to uncertainty of the potential for improving the recovery. Most crucially in order to improve all methods is a proper simulation of the mechanisms on a field scale.

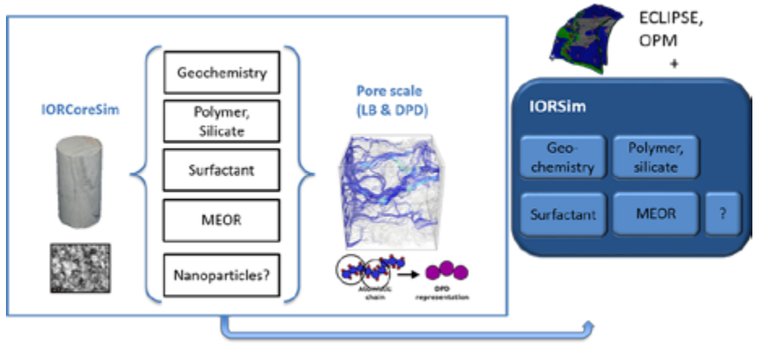


Figure:We develop models that are history matched to lab data and further refined by textural investigations, pore scale and molecular simulations. These models are included into IORSim, which is a an add on tool to eclipse. This allows us to combine the best of two worlds; using the latest models developed based on lab data in industry standard history-matched reservoir models.

THE RESEARCH:

After an initial phase where many projects where started we found it necessary to focus the work towards specific use cases. After an internal strategy process with the industry and The IOR Centre researchers we decided to aim for two pilot cases 1) Polymer injection in sandstone reservoir and 2) Smart Water injection in carbonates. We are working closely with the companies to try and identify specific wells where a pilot might be possible. We are well aware of that this might take some time; therefore we have also identified research tasks that will be more or less general and field independent. In particular we are working on identifying the specific mechanism related to Smart Water and developing better models for understanding the underlying parameters controlling shear degradation of synthetic polymers. Thus there are several projects dealing with characterization of minerals and surfaces at the pore scale and pore and nano scale simulations using the lattice Boltzmann and Diffusive Particle Dynamic (DPD) simulations. In parallel we are also working with numerical tools that can simulate the proposed mechanism from pore scale studies at the field scale. In particular the IORSim simulator, which we are developing, can be used together with commercial reservoir simulators to simulate novel IOR processes. The IORSim has the capability of incorporating advanced chemical and geochemical interactions that can be coupled to the flow field predicted by a commercial reservoir simulator (e.g ECLIPSE). The advantage with this approach is that we can build on history-matched reservoir models, which the companies has faith in and through the IORSim we can also incorporate our own research prototype IOR models that are calibrated to lab data.

In the figure, there is an overview of simulation models in Theme 1. Diffusive particle dynamics simulations are used to simulate IOR processes in single pores, lattice Boltzmann techniques are used to simulate in network of pores to obtain Darcy scale behaviour. These behaviour is compared with core scale experiments and submicron studies and combined into core scale models (IORCoreSim). To predict field behaviour we implement the models from IORCoreSim into IORSim. Doing this we get the best of two worlds; we can use mechanistic models that are based on core- and pore- scale data together with history matched industry standard reservoir models.

We are very pleased that one of our researchers has been invited to Japan to work with one of the world leading experts in submicron studies of minerals. She will stay there for 6 months. Two permanent positions at the University of Stavanger within experimental and theoretical reservoir physics with special focus on IOR were announced. We received many highly qualified applications and one person so far has been hired. He will start 1. March 2016.

SUMMING UP 2015:

2015 has been a very exciting year for us. We have performed several important studies, and with the help of our new tool, the roadmap, it is now easier to plan future projects. Listed below are two of the highlights from Theme 1 in 2015.

YARD-TEST:

When a polymer solution moves from the platform down to the reservoir, it will move through valves and constrictions. The polymer solution is then exposed to great forces; which in turn can lead to the long polymer molecules bust and the viscosity decreases. This means that you can lose a lot of the EOR effects before the polymer solution reaches the reservoir. The Centre, along with Halliburton, has tested standard valves and two special valves from Matek-Samson and SNF. The test has been successful; we have confirmed that a standard valve will reduce the polymer viscosity by approximately 60 percent. We have also identified three possible solutions to the problem.

IORSIM:

This modeling project started immediately after The Centre's startup in 2013. The existing reservoir simulation tools available on the market did not have the capabilities to simulate many of the IOR processes. The IORSim contains a geochemical model that makes it possible to simulate how the ion composition of pore water changes from injector to producer, and how this composition can affect the flow characteristics of oil and water. In practice, the IORSim is thought to be used as an application that can be connected to an industry standard reservoir simulator (e.g., Eclipse) to predict the effect of the IOR chemicals. This way, we can benefit from existing reservoir models that are history matched to the companies' production, but also include the latest IOR effects studied in The National IOR Centre. The IORSim can now be used on some realistic fields (such as Norne), and we are working together with Schlumberger to provide a good and effective feedback, meaning that the IORSim can predict how much oil flow properties change due to IOR effects. This information is sent back to the reservoir simulator.

TASK 1: CORE SCALE

"CLOSING THE KNOWLEDGE GAP ON EOR MECHANISMS AND POTENTIAL IS IMPORTANT. "

TASK LEADER: ARNE STAVLAND

WHAT ARE THE MAIN ASPECTS OF YOUR TASK?

The aim is to construct models that capture the transport mechanisms observed in core scale experiments.

THE 2015 PROJECTS:

We have been working on interpretation of core scale experiments through the project DOUCS (Deliverable of an Unbeatable Core Scale simulator) – development of tool for improved simulation of EOR processes at core scale. The main activity has been on modelling polymer behaviour in the high rate flow regimes; polymer elongation and shear degradation, supported by flood experiments. Part of the experimental work has been on comparing shear degradation at capillary tube and large scale, including interpretation of the results from a large scale yard test. Steady-state flood experiments of reservoir cores clearly revealed that the EOR potential by polymer flooding depends on the mobility ratio. Most of the EOR methods depends on the rock properties. To be able to correctly quantify the EOR potential from core flood experiments and also to compare different EOR methods rely on reliable rock properties, such as wetting conditions. One of the projects addressed the need of better core plug preparation procedures in EOR core flood experiments.

WERE ANY PROJECTS COMPLETED IN 2015?

A project in which we quantified how the combination of compaction and immiscible flow lead to changes in the oil-water saturation, permeabilities and the electrical resistance across the core. The four different volumes total bulk volume, pore volume, water and oil volume could be measured simultaneously. The results show that when compaction by pore collapse occurs, the microscopic sweep efficiency can be quantified by measuring the bulk volume, pore volume, and the oil and water volume.
The main conclusion of the IOR
screening study with SWORD based on current field data indicated that it is a huge potential for additional oil recovery with gas, especially HC-gas and CO2 for some of the fields on the NCS. However, detailed screening based on reservoir simulation and laboratory experiments needs to be performed to confirm the observations.

HOW DOES YOUR TASK CONTRIBUTE TO THE ROADMAP?

The task 1 projects are all highly relevant to the roadmap; where core scale simulation tool and demonstration of EOR mechanisms at core scale are some of the milestones.

HOW WILL YOU SUM UP 2015?

New PhD students have been integrated into the research activities. There has been a good cooperation between the different research partners and tasks and a strong involvement from the supporting companies. One example is the large scale test on polymer degradation performed by Halliburton, where the large scale test results matched well with laboratory scale experiments.

WHAT WILL YOU BRING WITH YOU TO 2016, AND THE FUTURE?

Closing the knowledge gap on EOR mechanisms and potential is important. Therefore, we address the need for laboratory scale experiments supported by larger scale experiments, EOR mechanistic studies on reservoir core material, the importance of core preparation procedures when estimating EOR-potentials at core scale. We will also continue the work on improving the core scale simulation model

DID YOU ATTEND ANY IMPORTANT MEETINGS, SEMINARS OR CONFERENCES IN 2015?

Yes, among others we attended the IEA Collaborative Project on EOR, the EAGE European Symposium of IOR, the SCA symposium and the SPE Oilfield Chemistry symposium. In addition, we attended the IOR NORWAY 2015 conference and workshop.

PAPERS PUBLISHED FROM TASK 1 IN 2015:

Fernø, M.A., Haugen, Å., Brattekås, B., Morrow, N.R. and Mason, G.: "Spontaneous Imbibition Revisited: A New Method to Determine Kr and Pc by Inclusion of the Capillary Backpressure", presented at *the EAGE 18th European Symposium on Improved Oil Recovery* held in Dresden, Germany, 14-16 April 2015.

Fernø, M.A., Haugen, Å., Brattekås, B., Mason, G and Morrow, N.R.: "Quick and Affordable SCAL: Spontaneous Core Analysis", Reviewed proceedings at *the International Symposium of the Society of Core Analysts*, St John's Newfoundland and Labrador, Canada, 16-21 August 2015.

Brattekås, B., Graue, A., Seright, R.S.: "Low Salinity Chase Waterfloods Improve Performance of Cr(III)-Acetate HPAM Gel in Fractured Cores", SPE 173749, presented at *the SPE International Oilfield Chemistry Symposium* held in the Woodlands, Texas, 13-15 April 2015. Accepted for publication in SPE Reservoir Evaluation and Engineering.

Steinsbø, M., Brattekås, B., Bø, K., Oppdal, I., Tunli, R., Ersland, G., Graue, A. and Fernø, M.A.: "Foam as Mobility Control for Integrated CO2-EOR in Fractured Carbonates", presented at *the EAGE 18th European Symposium on Improved Oil Recovery* held in Dresden, Germany, 14-16 April 2015.

Fernø, M.A., Gauteplass, J., Hauge, L.P., Ersland, G., Abell, G.E., Adamsen, T.C.H., Steinsbø, M., Brattekås, B. and Graue, A.: "Combined PET-CT for Visualization and Quantification of Fluid Flow in Porous Rock Samples", presented at the *Medviz conference 2015: Innovation in Imaging and Visualization* held at Haukeland University Hospital in Bergen, Norway, 15-16 June 2015.

Lohne, A.: "Simulation of laboratory experiments," presented at the *IOR Norway 2015 workshop*, Stavanger, Norway, 30 April 2015.

Stavland, A.: "How to improve models for evaluating the potential of polymer flooding," presented at the *IOR Norway 2015 workshop*, Stavanger, Norway, 30 April 2015.

Nermoen, A., Korsnes, R.I., Aursjø, O., Madland, M.V., Carlsen Kjørslevik, T.A. and Østensen, G.: "When time comes into play: How does stress and temperature conditions affect rock-fluid chemistry and mechanical deformation". *IEA Collaborative Project, 36th EOR Workshop & Symposium*, 6-9 September, 2015.

Nermoen, A., Korsnes, R.I., Fabricius, I., Storm, E.V., Stødle, T. and Madland, M.V.: "Extending the effective stress estimate to incorporate electrostatic effects". *Society of Exploration Geophysics (SEG) International exposition and 85th Annual Meeting*, 18-23 October, 2015.

Nermoen, A., Korsnes, R.I., Hiorth, A., Madland, M.V.: "Porosity and permeability development in compacting chalks during flooding of nonequilibrium brines: Insights from long-term experiment". *Journal of Geophysical Research - Solid Earth*, 2015 ;Volum 120.(5) s. 2935-2960.

Nermoen, A., Korsnes, R.I., Madland, M.V., Minde, M.W., Zimmermann, U., Hildebrand-Habel, T.: "How simple brine tests can be used to understand chalk core dynamics – Insights from long-term experiments". *IEA Collaborative Project, 36th EOR Workshop & Symposium*, 6-9 September, 2015.

Fjelde, I., Omekeh, A.O. and Minde, M.W.: "Removal of Mud Components from Reservoir Sandstone Rocks." Paper SCA2015-016, presented at the *International Symposium of the Society of Core Analysts*, St. John's Newfoundland and Labrador, Canada, 16-21 August, 2015.

Key personnel:

Arne Stavland (IRIS), Arild Lohne (IRIS), Merete Vadla Madland (UiS), Reidar Inge Korsnes (UiS), Ola Ketil Siqveland (UiS), Kim A. N. Vorland (UiS), Ingebret Fjelde (IRIS), John F. Zuta (IRIS), Alexey Khrulenko (IRIS), Dagfinn Sleveland (IRIS), Anders Nermoen (IRIS/UiS)

PostDocs:

Bergit Brattekås (UiS, UiB), Pål Andersen (UiS)

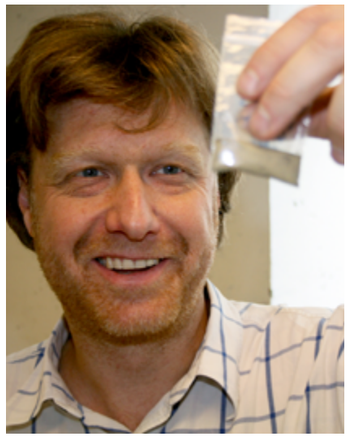
PhD students:

Oddbjørn Nødland (UiS/IRIS), Kun Guo (UiS), Irene Ringen (UiS/IRIS), Jaspreet Singh Sachdeva (UiS), Tijana Livada (UiS), Samuel Erzuah (UiS/IRIS)

TASK 2:

MINERAL FLUID REACTIONS AT NANO/SUBMICRON SCALE

"THIS RESEARCH IS EMBEDDED IN A WELL-FUNCTIONING INTERNATIONAL NETWORK OF STATE-OF-THE-ART LABORATORIES WHICH WILL ASSIST IN THE RAMAN RESEARCH"



TASK LEADER:
UDO ZIMMERMANN

WHAT ARE THE MAIN ASPECTS OF YOUR TASK?

What are the important alterations observed on nano-/micron scale that are important for changes in surface properties of rocks, such as wettability change? This implies the understanding of mineralogical changes after flooding test on reservoir type rocks.

How to quantify the properties of water and oil films coating mineral surfaces? The alterations could be textural changes, such as formation of secondary minerals or dissolution of primary minerals, or it could be changes in surface properties such as surface charge or water/oil films or it could be both. The latter will be addressed at a later stage of the task.

Applied objectives and research strategies are related to those key questions and focused on the two planned pilot projects according to the roadmap:

- mineralogical changes at nano-/submicron scale
- developing a tool box (including methodologies) to investigate quick and effective reservoir rocks after experiments (both chemical and clastic sedimentary rocks)

IN 2015 THE FOLLOWING PROJECTS HAVE BEEN CARRIED OUT:

New methodologies at The National IOR Centre of Norway for EOR purposes

We installed Raman spectroscopy as a routine method for the investigation of mineralogical composition of tested and untested samples and we started systematic measurement of the Specific Surface Area measurements (SSA). Both methodologies are key parameter to evaluate flooded rocks (chalk) for EOR purposes.

Raman spectroscopy is a method, which works with laser application, is non-destructive, very quick and extraordinary cheap – it has been, for unknown reasons, rarely applied to carbonate, which will be done here. The aim is to identify mineral changes in flooded chalk and in natural as well as forced fractures. Raman spectroscopy can determine nano-phases (nanoRAMAN) and micro-phases (microRAMAN) – both will be done (see 2016).

The correct methodology to measure the Specific Surface Area (SSA) on rocks has still yet to be defined. This seems surprising but several methods are applicable to measure the SSA without a systematic testing of the different methods for different rock types and types of samples (hand-milled, machine-milled, as a rock fragment). We will close this gap to develop a systematically tested methodology for any rock mechanical research and any EOR related test and finish this approach before summer 2016.

At this stage we have one manuscript ready and writing two others related to Raman and Specific Surface Area (SSA).

This research is embedded in a well-functioning international network of state-of-the-art laboratories which will assist in the Raman research (Universitá degli studi de Milano Bicocca, Italy for microRAMAN) and The Centre de Rècherche public Gabriel Lippmann (Luxembourg for nanoRAMAN)).

Geological studies on carbonates (including chalk) and chert for the further understanding of rock material for EOR research and applications

Here, we finished within The National IOR Centre of Norway several studies on carbonates, chalk, chert to understand better the mineralogical changes in reservoir rocks (of Cretaceous age) in northern Europe controlled by fluid flow process and paleoenvironmental parameter. As Task 2 is the only scientific approach concentrating on the geological processes those

projects had been very important to understand chalk and carbonates. This process cannot, which is obvious, deliver immediate results, because it is basic research and has been finished in 2015.

2016 is the year of compiling the data, presenting at conferences and writing publications.

Quantification of chemical changes in flooded chalk on homogenized and natural samples with FE-TEM at CoE Institute for the Study of the Earth's Interior (Misasa, Japan)
The major objective is quantification of chemical and mineralogical changes using a Field Emission Transmission Electron Microscopy (FE-TEM). The research assistant, MSc. Nina Egeland, who carries out that work in Japan for a 6 months long research stay, will bring extraordinary expertise to The National IOR Centre of Norway in this field of science. Nina Egeland is in Japan surrounded by absolute world-class scientists who publish regularly in nature. Hence, the expected results will be of highest quality. The project started with the preparation of samples for the 6 months stay and will be finished in Autumn 2016. This project will therefore deliver a method to apply Transmission Electron Microscopy (TEM) research on the quantification of new growth of minerals after flooding chalk. The data should also be able to understand the process of the mineralogical/chemical changes in terms of dissolution and precipitation. Several papers about homogenised and 'natural' chalk samples after flooding and a methodology to quantify chemical changes on nano-scale are envisaged. Last but not least, we will have as a result a fruitful and intensive collaboration with an international Center of Excellence on highest scientific level to educate young researchers in a scientific environment.

Quantitative SEM micrograph image analysis
This project promised to develop methods capable of capturing the essential ingredients of the morphological changes occurring on the grain-scale from compaction and flooding of reactive brines and has been led by Dr. A. Nermoen. The aim is to quantify changes as fluid-rock interactions occur. The project will finish in early 2016 and highlights how the flow of non-equilibrium brines change the microscopic morphology and described qualitatively. More objective quantitative measures are needed to understand the surface growth mechanisms. Changes to the Specific Surface Area, rock volume and porosity can be estimated independently. The project will contribute with image analysis software using Matlab that can be used in other projects.

WERE ANY PROJECTS COMPLETED IN 2015?
"New methodologies at The National IOR Centre of Norway for EOR purposes" will be finished early 2016. "Geological studies on carbonates (including chalk) and chert for the further understanding of rock material for EOR research and applications" has been finished and first manuscript will be expected in Summer 2016.

HOW DOES YOUR TASK CONTRIBUTE TO THE ROADMAP?
When translating core scale information to larger scale it is important that the mechanisms are understood. The IOR mechanisms usually depend on oil/brine/rock interactions. If the rock mineralogy is changed the effectiveness of the IOR method could be affected. In this task we focus on characterizing the rock, before and after flooding by IOR-fluids, with state of the art analytical tools..

"New methodologies at The National IOR Centre of Norway for EOR purposes" focuses on Raman and nano-raman combined with Atomic force microscopy (AFM) on any rock type and will run until autumn 2017.

We also focus on several methodologies on nano- and micron scale to monitor mineralogical changes and surface changes after engineering experiments in Task 2. Here, we combine Field Emission Gun Scanning Electron Microscopy/ Transmission Electron Microscopy, X-ray Diffraction, Electron microprobe analysis, Mineral Liberation Analyzer and stable isotope systems on the samples to be analysed. We are prepared for carbonate rocks and clastic samples. Especially the samples we have form Ekofisk will be studied and are perfectly in line with the roadmap. Results on those rocks will be of uttermost importance for the interpretation of a possible pilot project at Ekofisk.

"Geological studies on carbonates (including chalk) and chert for the further understanding of rock material for EOR research and applications" is on-going and concentrates on the quantification of mineralogical and chemical changes using FE-TEM and on a transfer of expertise from Japan to The National IOR Centre of Norway.

HOW WILL YOU SUM UP 2015?
It was inspiring and challenging because of the formulation of the roadmap and the need to adjust our projects to this focus.

WHAT WILL YOU BRING WITH YOU TO 2016, AND THE FUTURE?
We hope very much to contribute strongly with a) identification of mineral pahses using FE-TEM and nanoRaman on any sample material – b) finish the tool box for analyses - c) to reveal excellent data from Ekofisk core material which most probably will give valuable input to our IORSim, and d) to immediately focus on clastic rocks for polymer flooding.

DID YOU ATTEND ANY IMPORTANT MEETINGS, SEMINARS OR CONFERENCES IN 2015?

NGF Vinterkonferansen, Stavanger January 2015

European Conference on Mineralogy and Spectroscopy, Rome September 2015

IEA, IOR,, Japan

NPF 2015 Reservoir characterization, Stavanger

"LAST BUT NOT LEAST, WE WILL HAVE AS A RESULT A FRUITFUL AND INTENSIVE COLLABORATION WITH AN INTERNATIONAL CENTER OF EXCELLENCE ON HIGHEST SCIENTIFIC LEVEL TO EDUCATE YOUNG RESEARCHERS."

PAPERS PUBLISHED FROM TASK 2 IN 2015:

Zimmermann, U., Madland, M.V., Nermoen, A., Hildebrand-Habel, T., Bertolino, S.R.A., Hiorth, A., Korsnes, R.I., Audinot, J.-N. and Grysan, P. 2015 Evaluation of the compositional changes during flooding of reactive fluids using scanning electron microscopy, nano-secondary ion mass spectrometry, x-ray iffraction, and whole-rock geochemistry; *AAPG Bulletin 99*, 5, 791-805.

Wang, W.,* Madland, M.V., Zimmermann, U., Bertolino, S.R.A., Hildebrand-Habel, T., Korsnes, R.I., Nermoen, A., 2015. Revealing dynamic porosity: Evaluation of porosity during chemo-mechanical compaction in chalk from Liège (Belgium). *Geological Society of London Special Publication Reservoir Quality of Clastic and Carbonate Rocks: Analysis, Modelling and Prediction* (in press).

Abstracts:
Borromeo, L., Zimmermann, U., Andò, S., Coletti, G., Garzanti, E. 2015. Raman spectroscopy: an 'unconventional' and innovative tool to identify the mineralogy of chalk and other fine-grained rocks applicable to IOR research. *NGF Abstracts and Proceedings, Vinterkonferansen 2015,* 12.-14.1. 2015 Stavanger, 13-14.

Kallesten, E., Gomez, I., Moraleda, L.R., Zimmermann, U., Madland, M.V., Bertolino, S.R.A. 2015. Geological constraints on Cretaceous 'reservoir chalk' from the North Sea. NGF Abstracts and Proceedings, Vinterkonferansen 2015, 12.-14.1. 2015 Stavanger, 49.

Minde, M., Zimmermann, U., Madland, M.V., Audinot, J.-N., Grysan, P., Schulz, B., Haser, S., Korsnes, R.I., Gutzmer, J. 2015. Development of a natural fracture during flooding experiments for EOR purposes. *NGF Abstracts and Proceedings, Vinterkonferansen 2015*, 12.-14.1. 2015 Stavanger, 66.
Wang, W., Madland, M.V., Zimmermann, U., Hildebrand-Habel, T., Korsnes, R.I., Minde, M., Nermoen, A. 2015. Chemo-mechanical tests on chalk: resulting changes in geochemistry and mineralogy. NGF Abstracts and Proceedings, Vinterkonferansen 2015, 12.-14.1. 2015 Stavanger, 105.

Borromeo, L., Zimmermann, U., Andò, S., Coletti, G., Bersani, D., Basso, D., Gentile, P., Garzant, E. 2015. Raman Spectroscopy as a tool for magnesium estimation in Mg-calcite. *Periodico di Mineralogia (2015)*, 84, 2, 35-36

Key personnel:

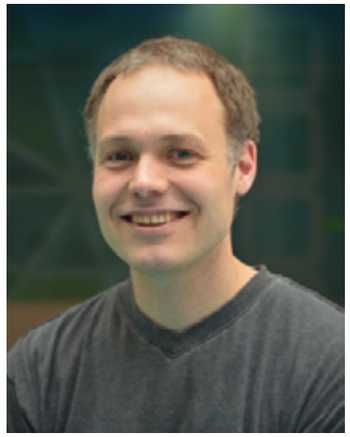
Udo Zimmermann (UiS), Silvana Bertolino (2015) (Guest researcher at UiS), Laura Borromeo (UiS, PhD student), Reidar I. Korsnes (UiS), Merete V. Madland (UiS), Mona Minde (UiS, PhD student), Wenxia Wang (UiS, PhD student),Nina Egeland (UiS), Ema Kallesten (UiS), Jacob Dieset (UiS)

Several lab/student assistants
A large group of international collaborators

TASK 3:

PORE SCALE

"THE HIGHLIGHTS FROM 2015 IS THE GENERATION OF REAL PORE SCALE GEOMETRIES, WHICH WILL BE IMPORTANT FOR THE MODELING WORK ON REACTIVE FLOW. "



TASK LEADER:
ESPEN JETTESTUEN

WHAT ARE THE MAIN ASPECTS OF YOUR TASK?

In task 3 we study the interplay between fluid transport, mineral reactions and oil recovery in reservoir rocks at pore scale. The main aspects are to identify the mechanisms that influence transport and reactions on the pore scale using experiments and numerical modeling, and then to evaluate if these mechanisms are important on the core scale.

THE 2015 PROJECTS:

There were 5 projects in task 3 this year:

Three-dimensional imaging and pore-scale modeling of carbonate rocks. This project was a collaboration between IRIS, UiS and Sandia National Laboratories. The main deliverables from this project were sets of carbonate rock pore scale geometries which were generated from gray scale SEM images of sliced rock samples. Maps of mineral content were also generated for selected geometries. This becomes the basis for the numerical modeling of transport and reactions in carbonate rocks.

Pore scale processes. To understand how to upscale the reactions and transport on pore scale we have to be able to capture the effects in a set of effective properties. The main aim of this projects was to identify the effective properties related to dissolution/precipitation processes.

Emulsions in porous media. This is phase two of the Task 2 project "Determination of droplet size distribution in oil- water emulsions passed through a porous material studied by low field NMR". This project focuses on how the stability of oil suspensions is affected by transport through porous media simulated by sand packs and filters.

Experimental investigation of the effect of fluid chemistry on the adhesive properties of calcite grains. This is an experimental PhD project on how forces between mineral surfaces in water change with the chemical composition of the fluid. The forces are measured by a surface force apparatus and the surfaces will be calcite-calcite and calcite-mica (a clay like surface).

Periodynamics simulation of chalk – from nanometers to centimeters. The project is part of a PhD project at the University of Oslo. Periodynamics simulations is a modeling technique that include multiple length scales in modeling the strength of rocks. We have supplied the PhD-candidate with an chalk geometry from the "Three dimensional imaging..."-project.

WERE ANY PROJECTS COMPLETED IN 2015?

Two projects were finished in 2015.

"Emulsions in porous media": The project went on to be part of a RCN petromaks application.

"Pore scale processes": The project was part of an UiS/IRIS PhD project that was successfully defended by candidate Janne Pedersen.

HOW DOES YOUR TASK CONTRIBUTE TO THE ROADMAP?

The task contributes to the understanding of "IOR mechanisms" and also "Development of IOR methods", which are both defined as key R&D activities in the map.

The task also contributes to upscaling results from pore to core, and should help to set reasonable effective rehologies and parameters. Methods to infer the large scale effects of pore scale mechanisms should also be a part of the interpretation tool-box.

HOW WILL YOU SUM UP 2015?

The highlights from 2015 is the generation of real pore scale geometries, which will be important for the modeling work on reactive flow.

The use of the numerical model from "pore scale processes" to interpret a long term core flooding experiment also gave us a good baseline for which pore scale effects that contribute at the core scale.

WHAT WILL YOU BRING WITH YOU TO 2016, AND THE FUTURE?

In 2016 we will continue our work on reactive flow using the geometries generated by Sandia National Laboratories in phase two of "Three-dimensional imaging and pore-scale modeling of carbonate rocks". The work on the strength of rock in the two PhD projects will continue as planned.

We will also focus more on polymer flooding using both molecular simulations (Teresa Palmer, PostDoc at UiS/IFE) and pore scale models for shear thinning fluids and upscaling to core scale.

DID YOU ATTEND ANY IMPORTANT MEETINGS, SEMINARS OR CONFERENCES IN 2015?

At IOR Norway 2015 Hongkyu Yoon (Sandia NL) presented their finding using FIB-SEM, and Shaghayegh Javadi (UiS/UiO) presented her use of SFA for studying the adhesive properties of chalk at the workshop.

Photo: Chalk geometries generated by Sandia National Laboratories in Phase 2 of "Three-dimensional imaging and pore-scale modeling of carbonate rocks".
Source: Hongkyu Yoon, Sandia National Laboratories, Albuquerque

PAPERS PUBLISHED FROM TASK 3 IN 2015:

Pedersen, Janne; Jettestuen, Espen; Madland, Merete Vadla; Hildebrand-Habel, Tania; Korsnes, Reidar Inge; Vinningland, Jan Ludvig; Hiorth, Aksel. ., "A dissolution model that accounts for coverage of mineral surfaces by precipitation in core floods". *Advances in Water Resources* (2016)

Key personnel:
Espen Jettestuen (IRIS,), Jan Ludvig Vinningland (IRIS), Aksel Hiorth (IRIS/UiS), Olav Aursjø (IRIS, PostDoc), Teresa Palmer (UiS/IFE, PostDoc), Roar Skartlien (IFE), Anja Røyne (UiO), Shaghayegh Javadi (UiS/UiO, PhD student), Hongkyu Yoon (Sandia NL), Anders Malthe-Sørennsen (UiO), Sigve Bøe Skattum (UiO, PhD student)

TASK 4:

UPSCALING AND ENVIRONMENTAL IMPACT

"THE CONTRIBUTION FROM THE SERVICE COMPANIES ARE EXTREMELY VALUABLE. IN PARTICULAR, IT HELPS US TO KEEP THE RESEARCH FOCUS APPLIED, WHICH WE NEED TO REACH OUR AMBITIONS"

TASK LEADER:
AKSEL HIORTH

WHAT ARE THE MAIN ASPECTS OF YOUR TASK?

The main objective of this task is to translate the knowledge we have about EOR processes on core scale to field scale. In the lab (and in Task 1-3) we have studied the systematics of oil recovery as a function of the injection of different fluids, and as a result of this we know a lot about how and why oil is released from reservoir cores. When we study these recovery mechanisms on a larger scale, there are several challenges. i) Practical aspects related to the preparation of injection fluids offshore, and treatment of produced fluids. ii) Field scale simulations of the EOR processes based on models that are consistent with the mechanisms observed on pore- and core-scale. iii) Reservoir characterising, such as knowledge about flow paths in the reservoir, and temperature gradients.

The deliverables from this task will be simulation models and work flows that are capable of translating lab scale results to field scale.

THE 2015 PROJECTS:

The projects aims at answering the main challenges described above. There are two PhD projects and one project led by Halliburton (described below) related to challenge i) described above: One PhD project is supervised by professor Bilstad and aims at determining how to produce the optimal (both in terms of economy and EOR effect) offshore using membrane technology. The second PhD project investigate the environmental fate and effects of EOR chemicals, with a special focus on polymer based chemicals.

In order to simulate EOR processes on field scale (challenge ii) and iii)), the main practical aspect is that mature reservoirs have a long and complicated production and injection history. The industry standard reservoir models that are capable of history match this production history, usually do not have the functionality to simulate the EOR mechanisms identified from pore- and core-scale investigations. To overcome this challenge, we develop a simulator - IORSim, where the EOR mechanisms identified at pore- and core-scale are implemented. This simulator uses the information about flow paths from the industry standard reservoir model, and predict changes in relative permeability, permeability, porosity and capillary pressure due to the EOR method and feeds this information back into the industry standard reservoir model. Thereby it is possible to predict the effect of the EOR methods we study in the Centre directly on realistic field cases.

WERE ANY PROJECTS COMPLETED IN 2015?

In 2015 we completed the large-scale polymer shear degradation test. This project was led by Halliburton and was performed at the Ullrigg test site, IRIS. The project was a success, which was only possible because we were able to build on expertise from service companies and chemical vendors. SNF contributed with polymer solutions, a choke, and equipment to perform the test, and skilled personnel during the test. Matek-Samson contributed with a special choke valve that was tested, and after the test SAR AS contributed to destroy the polymer solutions that was tested.

The main conclusion from this project was that chokes are not a showstopper for polymer injection, but that special care needs to be taken. The project identified three possible solutions to avoid shear degradation in chokes The results from this test was also compared with lab studies, in capillary tubes at laminar flow conditions. The results was not directly comparable with the large scale experiments. The reason for this was turbulent flow in the large scale test, which made it hard to evaluate a characteristic shear rate. However, when accounted for the different Reynolds number we were able to match polymer degradation obtained both at cm^3/min and m^3/min scales.
This is an important result, because it demonstrates that it is possible to obtain similar information from lab scale tests as from a large scale test.

HOW DOES YOUR TASK CONTRIBUTE TO THE ROADMAP?

This task contributes to demonstrate potential and prepare for pilot.

HOW WILL YOU SUM UP 2015?

The PhD students are integrated into the research activities. There has been a good cooperation between the different research partners and tasks and a strong involvement from the supporting companies. One example is the large scale test on polymer degradation performed by Halliburton, and also the release of field data which makes it possible to calibrate and test our simulation models. We have projects that involve IFE, UiS, and IRIS and the service companies. Halliburton is managing the large scale test, and Schlumberger supports in order to get IORSim to communicate efficiently with Eclipse.

WHAT WILL YOU BRING WITH YOU TO 2016, AND THE FUTURE?

The projects will continue. The large-scale test phase I is finished, but we will develop a similar concept in 2016, where the focus will be on what happens to the polymer chemicals when they enter the porous rock. Since the start of The IOR Centre, we clearly see that the contribution from the service companies are extremely valuable. In particular, it helps us to keep the research focus applied, which we need to reach our ambitions to contribute to EOR pilots on the NCS. Important for 2016 will be to continue the dialogue and collaboration with the user partners on field data.

DID YOU ATTEND ANY IMPORTANT MEETINGS, SEMINARS OR CONFERENCES IN 2015?

Yes, among others we attended the IEA Collaborative Project on EOR, IDA World Congress, 2nd International Conference on Desalination Using Membrane Technology, Advanced Membrane Technology 5th Conference. In addition, we attended the IOR Norway 2015 workshop and conference.

PAPERS PUBLISHED FROM TASK 4 IN 2015:

Hiorth, Aksel; Sagen, Jan; Haukås, Jarle; Lohne, Arild; Nossen, Jan; Vinningland, Jan Ludvig; Sira, Terje. "IORSim – a simulator for predicting the effect of rock fluid interactions on oil recovery based on industry standard reservoir models." *IEA Collaborative Project 36th EOR Workshop & Symposium;* 2015-09-07 - 2015-09-11

Bilstad, Torleiv; Hilman, Deannisa T; Protasova, Evgenia; Nair, Remya. Ionic Selection from produced water for IOR. *IDA World Congress;* 2015-08-30 - 2015-09-04

Hilman, Deannisa T; Protasova, Evgenia; Bilstad, Torleiv; Nair, Remya. Ionic Selection from produced water using NF membranes for IOR. *2nd International Conference on Desalination Using Membrane Technology*; 2015-07-26 - 2015-07-29

Nair, Remya; Protasova, Evgenia; Bilstad, Torleiv; Saltveit, Kjerstin J.. Designer Water by Membranes. *Advanced Membrane Technology 5th Conference;* 2015-02-08 - 2015-02-13

Nair, Remya; Protasova, Evgenia; Bilstad, Torleiv; Saltveit, Kjerstin J.. Improved oil Production by membranes. *AGH Drilling Oil Gas 2015* ;Volum 32.(1) s. 221-232

Key personnel:
Terje Sira (IFE), Egil Brendsdal (IFE), Jan Nossen (IFE), Jan Sagen (IFE), Arild Lohne (IRIS), Jarle Haukås (Schlumberger), Aksel Hiorth (UiS/IRIS), Arne Stavland (IRIS), Siv Marie Åsen (IRIS), Amare Mebratu (Halliburton), Remya R. Nair (UiS, PhD student), Evgenia Protasova (UiS), Torleiv Bilstad (UiS), Eystein Opsahl (UiS, PhD student) and Roald Kommedal (UiS), Dmitry Shogin (UiS, postdoc)

RESEARCH AND ACHIEVEMENTS IN THEME 2:

MOBILE OIL

– RESERVOIR CHARACTERISATION TO IMPROVE VOLUMETRIC SWEEP

Theme 2 works with the integration of field data such as pressure, temperature, seismic data, tracer data, geophysical data, and geological data into a field scale simulation model.

We will focus our research towards integrating all types of information/data available to improve and enhance decision-making in petroleum production. A main driver when conducting our research is to deliver new results and new methodology that will be applied by the industry.

PRIMARY OBJECTIVE OF THEME 2:

The aim is to develop new and improved methodology that will support the evaluation and decision making with regards to IOR/EOR pilots at the Norwegian Continental Shelf (NCS). This addresses the potential of producing the resources in unswept areas as well as mobilizing the trapped resources in swept areas. The research is focusing on challenges for the entire NCS while demonstrating the improved methodology on real field cases.

SECONDARY OBJECTIVES OF THEME 2:

- Further development of tracer technology
- Improvement of reservoir simulation tools with regards to IOR/EOR processes
- Robust production optimization
- Better history matching through improved data assimilation tools
- Inclusion of 4D seismic data in ensemble based history matching
- Evaluation of economic potential
- Investigation of the connection between the reservoir complexity and recovery factor potential

THE RESEARCH:

The tracer technology research of The Centre is focusing on the development of new tracers, both for single-well and inter-well tracer testing. Tracers injected in the reservoir can give unique information about swept volume and remaining reserves in flooded areas. This important information is used in decision-making regarding production strategy and investments, and especially when evaluating the potential of EOR-pilots. Inter well tracers are typically injected several times during the reservoir life time, and ideally one would like to inject different tracers at different times, and different tracers at different wells, to avoid that the tracer analysis are affected by rejected water containing "old" tracers. There are not enough tracers to do this today, and the industry is asking for more to be developed. The industry is also asking for more environmentally friendly tracers and tracers that can be detected at very low concentrations; both are essential when developing new tracers within The Centre.

There are several commercial reservoir simulators on the market today; some are commercially leading while some are developed to simulate special cases. Common for all these are that the licenses are expensive and that the source code is not available for the user. The latter can especially be a hinder when doing research to improve reservoir simulator tools. In addition, the biggest companies typically develop their own in-house simulators, which is a time consuming and expensive effort, and it can potentially lead to difficulties in the communication between companies if different in-house tools are used. One of the topics of The Centre is to contribute to the development of an open source reservoir simulator (OPM). This work is already well established and the code is available for all by downloading. This initiative covers the gap between academia and the industry, and it ensures that the research is moving fast forward without depending on commercial actors. It also would encourage the commercial tools available to improve. The open source development uses a framework where several national and international researchers from different research areas contribute. The developed simulator is industry friendly as it reads and writes files on Eclipse format. Within The IOR Centre the research is especially targeted towards more efficiently and correctly simulation of IOR/EOR and aims to make the results available in OPM.

Even using the most advanced tools and methods available we cannot know for sure how it looks like in the reservoirs. It is crucial for the operators to include the best possible estimate of the uncertainty of the reservoir when decisions about production, profitability, new investments, etc., are made. One of the main research topics within The Centre is the use of ensemble based methods in history matching and production optimization. Unique with ensemble based methods is the use of several reservoir models, an ensemble of reservoir models, and hence an uncertainty measure more consistent with the geological uncertainty can be retained. The method also ensures a workflow where a large amount of data can be assimilated and a large number of model parameters can be history matched (updated). The ensemble based methodology also enables the development on non-intrusive methods that can exploit the use of parallel processing and exploit advances in computational power. Essential in our research are the inclusion and uncertainty quantification of 4D seismic data, and to conduct this research IRIS work closely with University of Bergen, Schlumberger and TNO.

The optimization research in The Centre focus on improved methodology for optimizing the production strategy to improve volumetric sweep and to evaluate the economy of IOR/EOR projects. An ensemble of history matched models is be used to account for the uncertainty in the reservoir description and to obtain realistic uncertainty propagation onto the predicted production/behavior of the reservoir. The latter is especially important when evaluating the economy of a potential EOR project. The research is conducted in cooperation between IRIS, University of Stavanger and TU Delft.

SUMMING UP 2015:

NEW TRACERS:

In 2015 IFE has made progress on tracer development for both interwell tracer studies and single well tracer tests. 16 compounds have been selected for further testing for use in the interwell region and the main focus in 2015 on this subject has been the development of good analytical methods for the candidates. As tracer candidates for single well tracer studies ester lanthanide chelates have been selected. Synthesizing of different ester chelates have been the main focus in 2015.

OPM:

The open reservoir simulator developed by, among others, The National IOR Centre, has been further developed over the past year: Simulation speed is significantly improved, the full Norne model with all its Eclipse-keywords is successfully simulated, the code has been released on github.com twice during 2015, and polymer flooding is implemented and tested. One spin-off project to increase the speed of OPM even more was started at IRIS in 2015.

4D SEISMIC DATA-ASSIMILATION:

IRIS, the University of Bergen, Schlumberger and TNO in the Netherlands are working together to develop methods for including the information from 4D seismic data in history matching. One of the methods tested in 2015 consists in estimating pressure and saturation fields from seismic data and use it in the history matching. Moreover,Primary-wave to Primary-wave Amplitude Versus Offset (PP-AVO) data were used to estimate pressure and saturation on a test case. The results were promising and we have now received real data from the Ekofisk field to test the method further.

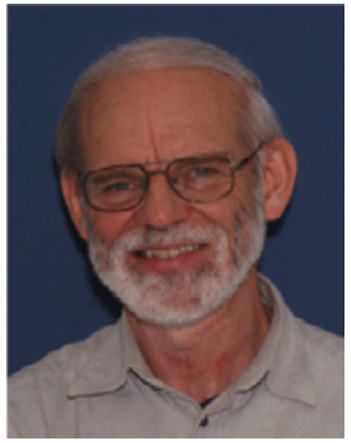
OPTIMIZATION:

Through the joint work with TU Delft and TNO a theoretical investigation on ensemble based optimization has resulted in new methodology that speeds up the algorithm significantly. This research has led to a spin-off project started at IRIS in 2015 to test the new methodology on a real field case.

ECONOMICAL POTENTIAL:

A final report on economic potential of IOR/EOR was delivered in 2015. A realistic evaluation of the economic viability is essential to any IOR/EOR projects. During execution of the project, decision criteria in the oil companies have changed. When the oil price fell, oil companies implemented stricter capital rationing, first in the form of net present value indexes. When the oil price proved to be more volatile, they shifted to break-even prices. IOR-projects that had problems being funding at the outset, now obviously struggle even more. The project has described changes in company decision criteria and the effect on investment incentives in general, and for IOR-projects in particular.

TASK 5: TRACER TECHNOLOGY



TASK LEADER:
TOR BJØRNSTAD

"THE OBJECTIVE IS THE DEVELOPMENT OF TRACER TECHNOLOGY TO MEASURE RESERVOIR PROPERTIES AND (CHANGING) CONDITIONS DURING PRODUCTION. "

WHAT ARE THE MAIN ASPECTS OF YOUR TASK?

The objective is the development of tracer technology to measure reservoir properties and (changing) conditions during production. The most important condition is the (remaining) oil saturation, either in the flooded volume between wells (interwell examinations) or in the near-well region out to some 10 m from the well (single-well huff-and-puff examinations). The deliverables from this task will be field-applicable methods and procedures to carry out such tracer-based measurements in reservoirs.

THE 2015 PROJECTS:

In 2015 one post.doc (50%) has been working on fluorescent tracers, mainly rare earths chelates and C-dots (in cooperation with Cornell University). In principle, these compounds may be applied both in interwell and single-well examinations. One post.doc (50%), along with other IFE researchers, have been working mainly with C-dot nano particles.

A PhD-student started work in April 2015. His focus is on phase-partitioning tracers which can be used in interwell examination. His timeline stretches over 3 years. The achievements in 2015 are summed up below:
- PhD student hired by March/April 2015
- Study program approved by UiS May/June
- Theoretical studies (courses) started (UiS)
- Thorough literature survey conducted on possible chemical compounds
- Originally 30 selected for further evaluation
- Finally 16 selected for studies in the lab,- already started: analyzability, thermal stability, chemical stability, microbial stability, sorption to rock, dynamic flow properties.

Goal: At least 5 new tracers with acceptable properties.

DID YOU COMPLETE ANY PROJECTS IN 2015?

Our development follows the roadmap of The National IOR Centre of Norway. None of the subtasks were expected to be finished in 2015, and work continues as planned.

HOW WILL YOU SUM UP 2015?

2015 has moved the technical development in task 5 forward, and we estimate to be on track and on time.

WHAT WILL YOU BRING WITH YOU TO 2016, AND IN THE FUTURE?

2016 will be the first year where we can report on conclusive results of specific detailed and defined work packages or research topics for each of the subtasks of Task 5. We will also consider hiring a post.doc (50%) to continue work on C-dots and other types of nanoparticles. If intermediate results are sufficiently positive, we will consider to propose, and prepare for, a field pilot tracer test, preferably in a small-size reservoir with easy-to-operate wells.

DID YOU ATTEND ANY IMPORTANT MEETINGS, SEMINARS OR CONFERENCES IN 2015?

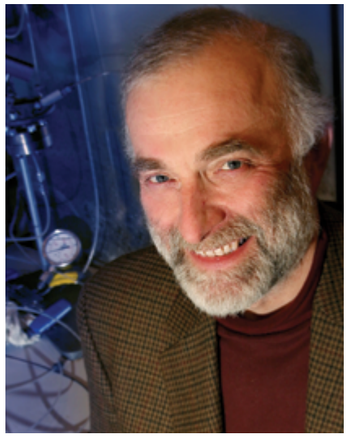
The whole tracer team (7 persons) with some relation to The National IOR Centre of Norway attended the Conference IOR NORWAY 2015, University of Stavanger, 28-29 April 2015.

Tor Bjørnstad: "Radiotracers Applications in Oil Fields: Enhancing the Recovery of Oil", invited talk, in proc. "IAEA General Conference 2015-Scientific Forum: Atoms in Industry – Radiation Technology for Development", IAEA, Vienna, 15-16 September 2015

Tor Bjørnstad: "Nanoparticle-based Tracers in Industry", invited talk, in proc. "Nanotracer Development and Applications in Multiphase Flow Investigations", IAEA, Vienna, November 2-6, 2016, p.76

Key personnel:
Tor Bjørnstad (IFE), Thomas Brichart (IFE, Postdoc), Mürside Kelesoglu (IFE, Postdoc), Mario Silva (UiS&IFE PhD student)
Alexander Krivokapic (IFE), Sissel Opsahl Viig (IFE)

TASK 6: RESERVOIR SIMULATION TOOLS



TASK LEADER:
SVEIN SKJÆVELAND

TASK LEADER:
ROBERT KLOEFKORN

"2015 WAS A VERY SUCCESSFUL YEAR WITH 8 PAPER PUBLICATIONS AND 3 SOFTWARE RELEASES ACHIEVED BY RESEARCHERS IN TASK 6."

WHAT ARE THE MAIN ASPECTS OF YOUR TASK?

The primary objective is to provide innovative simulation capabilities to support needs arising from the other tasks within The IOR Centre. Secondarily, we hope to contribute to the general state of the art regarding simulation methodology.
One focus is the development and improvement of an open source state of the art reservoir simulator. Task 6 is devoted to contribute to the Open Porous Media (OPM) Initiative (www.opm-project.org). A second focus is the mathematical modeling of upscaling between core scale and field scale with main focus on brine-dependent EOR in fractured reservoirs with an implementation in OPM. Other deliverables will be papers, conference presentations and tutorial for the developed reservoir simulator.

THE 2015 PROJECTS:

Reservoir Simulation Tools

The main effort has been contributions towards the Open Porous Media (www.opm-project.org) simulation framework. This provides open source code able of handling industrial relevant models, thus offering a flexible environment for testing out new modeling concepts and methodologies. Another main goal of the project is to improve the geological / chemical description in the reservoir simulators. Aiming at creating a simplified chemistry system that can capture the lab behavior and is efficient enough to be applied in a field simulator. The proof of the concept will be done through history matching lab data and upscaling by comparison with numerical code.

Modeling of Near Well Zone Scenarios

Simulating coupled dynamical processes in the well and near-well zone is a relatively new area which has been constantly growing the past 15 years. There is a lack of adequate simulation tools for near-well tracer and chemical experiments, and the market potential for such studies are large. After a coupling of a reservoir simulator with a simple well model we can simulate and interpret tracer studies of the near well zone. In particular we plan to use the data assimilation techniques of Task 7 for better interpretation and utilization of the information in the field setting.

DID YOU COMPLETE ANY PROJECTS IN 2015?

Both projects in Task 6 – Reservoir Simulation Tools and Modeling of Near Well Zone Scenarios – continue beyond 2015.

All projects being run at IRIS continue beyond 2015. OPM re-

"WE MADE SIGNIFICANT CONTRIBUTIONS TO THE OPM DEVELOPMENT INCLUDING PARALLELIZATION AND PERFORMANCE AS WELL AS TO THE PROPOSED POLYMER AND CO_2 ACTIVITIES."

leases 2015.04 and 2015.10 were accomplished. Applicability for field scale models was proven (Norne). Performance of the simulator was addressed with significant improvement. To increase collaboration between Tasks in The IOR Centre OPM is now used as one of the reservoir simulator for history matching activities in Task 7. For the Near Well Modeling we developed a test case that was tested with the OPM simulator. Missing functionality was discovered that is to be added in 2016. A paper on higher order methods for polymer flooding was finished and submitted.

The Chemical Components & Temperature sub project run at UiS was finished. The main result was submitted to Chemical Engineering Science and accepted for publication in 2016. Furthermore, a paper 'A model for wettability alteration in fractured reservoirs' in SPEJ was published and a poster presentation 'An Analytical Model for Imbibition Experiments with Porous Plate' was held at the 18th European Symposium on Improved Oil Recovery.

HOW DOES YOUR TASK CONTRIBUTE TO THE ROAD MAP?

Sophisticated simulations tools like OPM are of utmost importance for The IOR Centre and the planned full field tests. Despite existing commercial simulation tools The IOR Centre supports an open software concept that allows for easy collaboration between research institutes and industry partners. Direct access to the source code allows for detailed problem analysis in cases of failure and also challenges commercial vendors to improve their simulation tools. Task 6 contributes to the following road map milestones: Upscaling, simulation and interpretation tools; Full field prediction; Field performance; Economic potential and environmental impact; Monitoring tools and history matching (by providing a tailor made forward simulator)

HOW WILL YOU SUM UP 2015?

2015 was a very successful year with 8 paper publications and 3 software releases achieved by researchers in Task 6.

We made significant contributions to the OPM development including parallelization and performance as well as to the proposed polymer and CO_2 activities. The OPM research activities in Task 6 are recognized and valued and moreover an industry project has been granted and started to strengthen the OPM development even further. We are also happy to have hired an excellent candidate for the proposed PhD project within Task 6 which starts in 2016.

One paper was published in SPEJ and another paper was presented at the 18th European Symposium on Improved Oil Recovery. Several other manuscripts have been prepared and are hopefully accepted in 2016.

WHAT WILL YOU BRING WITH YOU TO 2016 AND THE FUTURE?

We will continue our joined efforts to improve simulations tools within The IOR Centre.

OPM development will continue at a high level. We will extend our collaboration within The IOR Centre - with Task 4 by coupling OPM and IORSim and with Task 1 by investigating a coupling of OPM with IORCoreSim. Achievements in improvement of reservoir model formulation (UiS) and improved/novel numerical schemes (IRIS) will be made available in OPM.

The paper 'A Model for Reactive Flow in Fractured Porous Media' was accepted by Chemical Engineering Science this January. One paper is sent for review to Transport in Porous Media, three papers are in progress and could be submitted for journals during February or March. This includes an extended version of the conference paper from Dresden, April 2015.

DID YOU ATTEND ANY IMPORTANT MEETINGS, SEMINARS OR CONFERENCES IN 2015?

Researchers from Task 6 have been very active in 2015 and visited many different workshop and conferences. One researcher was granted a research visit to the US.

OPM workshop in Trondheim (March 2015)

Workshop on Galerkin Methods in Edinburgh (March 2015)

IOR NORWAY 2015

SIAM Geosciences in San Francisco (June 2015)

DUNE User Meeting in Heidelberg (September 2015)

American Geophysical Union Fall Meeting 2015

Research Visit NCAR Nov 2015 – Jan. 2016

18th European Symposium on Improved Oil Recovery in Dresden (March 2015)

SOFTWARE RELEASES:

Flornes, Kristin Margrethe; Lie, Knut-Andreas; Rustad, Alf Birger; Bao, Kai; Blatt, Markus; Brodtkorb, André R.; Brudevoll, Edvin; Fløysand, Christine; Hove, Joakim; Klöfkorn, Robert; Kvarving, Arne Morten; Lauser, Andreas; Rasmussen, Atgeirr Flø; Sandve, Tor Harald; Skaflestad, Bård; Sævareid, Ove. The Open Porous Media Initiative -- Release 2015.04. www.opm-project.org, 2015

Flornes, Kristin Margrethe; Lie, Knut-Andreas; Rustad, Alf Birger; Bao, Kai; Blatt, Markus; Brodtkorb, André Rigland; Fløysand, Christine; Gundersen, Fredrik; Hove, Joakim; Klöfkorn, Robert; Kvarving, Arne Morten; Lauser, Andreas; Rasmussen, Atgeirr Flø; Sandve, Tor Harald; Skaflestad, Bård; Sævareid, Ove. The Open Porous Media Initiative -- Release 2015.10. www.opm-project.org, 2015

Blatt, Markus; Dedner, Andreas; Engwer, Christian; Fahlke, Jorrit; Gersbacher, Christoph; Gräser, Carsten; Grüninger, Christoph; Kempf, Dominic; Klöfkorn, Robert; Nolte, Martin; Müthing, Steffen; Sander, Oliver.
The Distributed and Unified Numerics Environment -- Release 2.4. www.dune-project.org, 2015

PAPERS PUBLISHED FROM TASK 6 IN 2015:

Andersen, Pål Østebø; Evje, Steinar; Kleppe, Hans; Skjæveland, Svein Magne. A Model for Wettability Alteration in Fractured Reservoirs. *SPE Journal 2015* ;Volume 20.(6) p. 1261-1275

Evje, Steinar; Wen, Huanyao. Analysis of a Compressible Two-Fluid Stokes System with Constant Viscosity. *Journal of Mathematical Fluid Mechanics 2015* ;Volume 17.(3) p. 423-436

Evje, Steinar; Wen, Huanyao. Global Solutions of a Viscous Gas-Liquid Model with Unequal Fluid Velocities in a Closed Conduit. *SIAM Journal on Mathematical Analysis 2015* ;Volume 47.(1) p. 381-406

Evje, Steinar; Wen, Huanyao. On the large time behavior of the compressible gas–liquid driftflux model with slip. *Mathematical Models and Methods in Applied Sciences 2015* ;Volume 25.(11) p. 2175-2215

Omekeh, Aruoture Voke; Friis, Helmer Andre`; Evje, Steinar; Fjelde, Ingebret. A MODEL FOR LOW SALINITY FLOODING EXPERIMENTS: DISSOLUTION AND ION EXCHANGE. *Journal of Porous Media 2015* ;Volume 18.(3) p. 189-213

Bao, Lei; Klöfkorn, Robert; Nair, Ram D. Horizontally Explicit and Vertically Implicit (HEVI) Time Discretization Scheme for a Discontinuous Galerkin Nonhydrostatic Model. *Monthly Weather Review 2015*;Volume 143.

Dedner, Andreas; Klöfkorn, Robert. On Efficient Time Stepping using the Discontinuous Galerkin Method for Numerical Weather Prediction. *IOS Press 2015* 11 p.

Jehl, Markus; Dedner, Andreas; Betcke, Timo; Aristovich, Kirill; Klöfkorn, Robert; Holder, David. A Fast Parallel Solver for the Forward Problem in Electrical Impedance Tomography. *IEEE Transactions on Biomedical Engineering 2015 ;Volume 62.*(1) p. 126-137

Key personnel:

Robert Klöfkorn (IRIS), Svein Magne Skjæveland (UiS), Steinar Evje (UiS), Ove Sævareid, (IRIS), Pål Østebø Andersen (UiS, PostDoc) Trine Solberg Mykkeltvedt (IRIS, PostDoc) Anna Kvashchuk (UiS/IRIS, PhD student), Mohan Sharma (UiS/UiB, PhD student)

TASK 7:

FIELD SCALE EVALUATION AND HISTORY MATCHING

"NOW THERE ARE A LOT OF ACTIVITIES GOING ON, AND PHD STUDENTS, POSTDOCS AND THE RESEARCHERS HAVE NOW STARTED TO PUBLISH RESULTS FROM THE WORK WITHIN THE RESEARCH CENTRE."

TASK LEADER:
GEIR NÆVDAL

WHAT ARE THE MAIN ASPECTS OF YOUR TASK?

We are focusing on history matching using 4 D seismic data, which means that we are tuning reservoir parameters (permeability, porosity, etc.) in the reservoir simulation models such that the simulations are matching the actual observations better. We are using ensemble based methods to this. That means that we are running with a set (an ensemble) of different realizations of the parameter set and use statistical methods to tune the parameters. The outcome is then a set of reservoir simulation models that are better aligned with the actual observations from the field.

These reservoir simulation models can then be used for decision making and optimization of the future production. This leads to another part of our work, robust production optimization. In this activity we are improving the methodology for finding the optimal way of producing the reservoir, given the fact that uncertainty in the reservoir model is accounted for by using an ensemble of different reservoir models. Currently we are mostly focusing on the general methodology, but in future work we plan to focus more on optimizing EOR injection strategies.

We also have activities focusing on compaction effects, which is very important for some of the reservoirs at the Norwegian Continental Shelf. Including compaction in the modeling will be important in interpreting 4D seismic, as the effects of compaction must be discriminated from the effects from changes in pressure and saturation.

Finally, there is an activity on evaluation of the economic potential of IOR/EOR projects. This may be viewed differently from a societal and a company perspective. The tax rules is also of importance for a company in their prioritization between different activities.

THE 2015 PROJECTS:

Robust production optimization – PhD study Aojie Hong

A new idea on using the Capacitance-Resistive Models (CRMs) for rapid robust production optimization has been investigated. The result of using the CRMs was compared with that of traditional grid-based reservoir simulations showing promising results for improving the computational efficiency of ensemble-based production optimization focusing on water flooding. The results will be published in a conference paper in August 2016. Planned further studies is on using CRMs for ensemble based closed-loop production optimization and Value of Information (VOI) calculations.

Robust production optimization – PhD study Yiteng Zhang

Gradient free algorithms for production optimization or optimization of EOR processes under geological uncertainty has gained a lot of interest in the petroleum industry over the last years. Although the number of publications has started to grow, the theoretical understanding of the practical algorithms is still limited. In addition it is not clear what is the best objective function to optimize nor how to parametrize the controls in an efficient way. The objective of this project is to give a precise mathematical formulation of ensemble based optimization under geological uncertainty. Furthermore, the project aims at improving the existing methodology using more sound mathematical insight. The secondary objective is to understand and improve the formulation of the objective function under uncertainty and investigate the effect uncertainty has on several different parametrizations of the problem formulation.

Robust production optimization – cooperation with TU Delft and TNO

This project aims at cooperation between Andreas S. Stordal, IRIS and researchers at TU Delft and TNO on developing the methodology of ensemble based optimization. Andreas S. Stordal stayed 6 weeks in The Netherlands during 2015, and the joint work has resulted in several conference and journal papers.

Data assimilation using 4D seismic data

In this project we are aiming at utilizing 4D seismic data to improve the quality of the reservoir simulation models. Ensemble based methods have been developed for history matching (tuning of parameters in the reservoir simulation models) both using production data and tracer data. Including 4D seismic data in this framework is still challenging. There are several questions to be explored to understand why and how to use the knowledge to utilize the 4D seismic data for history matching. One aspect is to find the proper weighting between production data and 4D seismic data. The ensemble based methodology is based on a statistical approach, requiring a reasonable quantification of the uncertainty of the 4D seismic data. This is not straightforward, and one of the directions of research has been to improve on this uncertainty quantification. Another issue is the fact that the 4D seismic data sets are very large. We are currently investigating if a wavelet technique can be used both to compress the data and remove the most noisy part of 4D seismic data.

Data assimilation using 4-D seismic data – implementing TNOs approach on a field case (PostDoc)

TNO has earlier implemented and tested the use of an approach where the 4D seismic data are interpreted as information about the changes in the waterfront during production. This interpretation of the changes in the waterfront has then been used for history matching using ensemble based methods. This approach shows promise on synthetic cases. In this PostDoc project (Yanhui Zhang is the PostDoc) one is aiming to bring the methodology further to be applicable on actual field cases and the PostDoc of the project is working together with researchers at TNO to achieve this, first on the Norne field case.

Improved history matching under compaction

This project aims at improving the usage of time-lapse seismic data for compacting reservoirs. Time-lapse amplitudes and travel times changes are used to estimate pressure-saturation changes in the reservoir. The inverted seismic data might be used (either as time-lapse amplitude changes or as interpreted saturation and pressure changes) for updating of the reservoir simulation model. To fit this with the ensemble based methodologies a focus is paid on the uncertainty quantification of the inverted seismic data. We are currently looking into a real data set from Ekofisk, bringing further earlier work done by the PostDoc of the project, Tuhin Bhakta.

4D seismic and tracer history matching of coupled geomechanical / reservoir flow models

This project is the main part of Schlumberger's in-kind contribution to The IOR Centre, focusing on 4D seismic analysis and coupled models. A coupled model combines the reservoir flow model with a geomechanical model of the reservoir and the surrounding rock. Coupled models enable simulation and history matching of fault and fracture reactivation, compaction, dilation and seabed subsidence. As part of the project, a new methodology referred to as "Dynamic boundary conditions from 4D seismic data" has been developed. Instead of predicting reservoir compaction using the full field coupled model with a set of yield criteria, the displacement at top reservoir is inferred from 4D time shifts and used as a boundary condition for the overburden geomechanical model. This enables a more consistent mismatch analysis with respect to 4D seismic. Consequently, the R-factor rock physics model can be improved and material parameters can be updated in a novel way. In addition, progress has been made on establishing a relationship between the coupled models and the sediment distribution predicted by geological process modeling. 4D seismic analysis, including time shift and time strain estimates and compensating for compaction and time shifts in 4D amplitude analysis, is offered as support to other projects within The IOR Centre. Schlumberger is currently collaborating with IRIS on the 4D analysis for the project "Improved history matching under compaction".

In addition, part of Schlumberger's in-kind contribution has been used to develop a framework for coupling geochemical effects calculated by IORSim to Eclipse (task 4). Including tracers and/or ions in 4D history matching has not been a focus so far, but extending existing methodology in that direction is an interesting subject of future research.

Economic potential of IOR/EOR processes

This project has evaluated the economic viability of IOR/EOR projects on the NorwegianContinental Shelf. The project has described changes in company decision criteria (due to the resent marked change) and the effect on investment incentives in general, and for IOR-projects in particular. Output has been in the form of publications. Much effort has also been made to present these insights to the public in the form of newspaper interviews and presentation on conferences. In addition, a number of presentations have been held for the Centre and its members, so that the economic implications of their research has been clarified. Another part of the project has been to analyze the impact of governmental taxation on IOR/EOR projects and whether targeted tax changes can be made for such projects. IOR/EOR projects in mature fields often have a marginal profitability to companies, but to society, the net present value will be higher, partly due to a lower discount rate, and partly due to the fact that society benefits from gains achieved in all licenses. A comparison between taxation in Norway and the UK has been performed. The study shows that the UK tax changes are in accordance with the current business cycle meanwhile Norway is at odds with it. There are several rea-

sons for this, such as: Stable taxes in Norway compared to the UK; the fact that the Norwegian shelf is less mature than the UK shelf; non-favorable petroleum tax system in Norway compared to other petroleum extraction countries. Finally, it was noted that current Norwegian tax policy is inconsistent in that it presumes two different investment methods, one for onshore companies and quite another for oil companies.

WERE ANY PROJECTS COMPLETED IN 2015?

Yes, the project on economic potential of IOR/EOR processes was finished by December 2015. A final report is delivered.

HOW DOES YOUR TASK CONTRIBUTE TO THE ROADMAP?

4D seismic monitoring and history matching is key in understanding the effect of injection and production on the reservoir and the surroundings, and is required to properly evaluate the effect of a given IOR method in the field (pilot or full field test). Production optimization will be important for planning of the EOR processes to select the strategy to be followed which will influence the selection of wells for a pilot study.

HOW WILL YOU SUM UP 2015?

During 2015 more momentum was gained for the projects. In some cases because of recruitment of PhDs and PostDocs, but also because our research became more focused. In the second full year of the project, results from our work are starting to be published. In addition, there has now been some time to get some working collaboration across the institutions. Also, we have received some data set to work on from the industrial participants of The IOR Centre, including a data set from Ekofisk. Our focus on 4D seismic led to a conference presentation on better estimation of pressure-saturation changes from time lapse Primary-wave to Primary-wave Amplitude Versus Offset (PP-AVO) data. The work behind this conference paper focused on compacting reservoirs, and we now plan to use the ideas developed on the data set from Ekofisk. Within production optimization a cooperation between IRIS, TNO and TU Delft led to a journal paper giving better understanding of the theoretical properties of ensemble-based optimization. Statoil found these results very encouraging and requested IRIS to implement and do further studies in this direction. This led to a spin off project in 2015.

WHAT WILL YOU BRING WITH YOU TO 2016, AND THE FUTURE?

Now there is a lot of activities going on, and PhD students, PostDocs and the researchers have started to publish results from the work within The Centre. This will make our contribution more visible for the coming years. The fact that we also have field data available should enhance the quality of the research done and also motivate the researchers by seeing the actual applications of their work.

DID YOU ATTEND ANY IMPORTANT MEETINGS, SEMINARS OR CONFERENCES IN 2015?

IOR NORWAY 2015

"Petroleumsnæringen og Norges framtid", conference organized by NFR at NTNU 26.10.2015.

SIAM Conference on Mathematical and Computational Issues in the Geosciences, June 29 – July 2, 2015, Stanford University, Stanford, California USA

The 10th ENKF Workshop, June 20 – 22, Flåm, Norway

PAPERS PUBLISHED FROM THIS TASK IN 2015:

Bhakta, Tuhin. Better estimation of pressure-saturation changes from time-lapse PP-AVO data by using non-linear optimization method. *SEG Annual meeting;*

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HIGHLIGHTS 2015

On the following pages are some examples of research and development activities in The Centre. We work closely with the user partners, as well as with international and national collaborators.

THE UPSCALING TOOL IORSIM

BY TERJE SIRA, JAN SAGEN AND AKSEL HIORTH

"THIS TOOL CAN BE CALIBRATED TO CORE SCALE EXPERIMENTS, AND THEN BE USED TOGETHER WITH AN INDUSTRY RESERVOIR SIMULATOR TO PREDICT THE EFFECT ON FIELD SCALE."

Rock fluid interactions are very important for most of the water based EOR methods. However, industry standard reservoir models, such as Eclipse, does not have any option to account for these effects. To solve this challenge, the program IORSim is being developed. This tool can be calibrated to core scale experiments, and then be used together with an industry reservoir simulator to predict the effect on field scale.

We believe that IORsim can answer the following question: How does a certain IOR strategy (injection of smart water, polymers etc.) translate from core scale to the drainage of a specific reservoir and the total production of hydrocarbons?
The program is being implemented as a plug in to Eclipse as shown in the figure below.

Figure 1: IORSim is coupled to Eclipse via restart files

IORSim is coupled to Eclipse via Eclipse restart files. Almost all the input to IORSim is read from Eclipse files. Only a fairly small amount of additional input (IOR chemical species concentrations in the injection water etc.) is read from a separate IORSim input file.

During simulation Eclipse integrates one time step and the new reservoir flows are read into IORSim. Based on the flow velocities IORSim advects the IOR species in the reservoir, taking into account equilibrium relations and chemical reactions and the interaction with the reservoir rock.

The IOR chemical behavior is implemented in a sub model (Geochemistry) with a standardized interface. This means that the geochemistry is easily replaceable (i.e. lo sal water, polymers). The geochemistry model also has to compute the changes in flow properties due to the IOR chemicals. This information is then transmitted back to Eclipse and used for the next time step. For the time being only changes in relative permeability are being considered, but other properties may also be included.
In this way the effects of the IOR chemicals on the production of the reservoir is included. The main idea behind IORSim is that if there is an updated reservoir model for a field, the effect of an IOR scenario can be simulated by plugging in IORSim and specifying the IOR scenario. The main reason Eclipse has been chosen as the most widely reservoir model, is in the North Sea. IORSim could also be coupled to other reservoir models, and there are plans to couple IORSim to OPM.
Some highlights of the development work in 2015 are:

THE SOLUTION METHOD

In IORSim, an implicit sequential method is used for solving the coupled equations for species transport and chemical reactions. Instead of solving implicit equations for all grid blocks simultaneously, the blocks are sorted sequentially along each of the "flow streamlines". This sorting algorithm is independent of the method applied to calculate the flow, hence it applies equally well to a full field reservoir simulator as to a more simple streamline simulator. By solving the species transport and reactions for upstream blocks first, the whole transport problem may be solved implicitly without solving for all blocks simultaneously. Iterations are only performed for the geochemical model on the local block level. The overall method is analogous to solving a specific linear equation system by sorting the equations in a favorable sequence so that only back substitution is needed to solve the system.

THE GEOCHEMICAL MODEL

The geochemical model that is implemented in IORSim is based on the Helgeson-Kirkham-Flowers (HKF) equation of state. This equation of state is capable of calculating thermodynamic properties of minerals, aqueous species and gases from 1 to 5000bar and 0 to 1000ºC, and has been successfully applied in the geosciences to describe mineralogical alterations observed in nature. We have applied the same techniques to describe chemical interactions in core floods, and to interpret increased oil recovery due to rock fluid interactions.

BACK COUPLING TO ECLIPSE

The rock fluid interactions induced by the injected water cause changes in the flow properties of the rock, IORSim is capable of predicting these changes. However, this information needs to be passed back to Eclipse, and has been a an important task in 2015 (and will continue in 2016). This is far from straight forward. In this work we have had excellent expert help from Jarle Haukås in Schlumberger. A working prototype has been established for the back coupling of smart water and the effect of the relative permeability.

THE TEMPERATURE EQUATION

Many Eclipse models do not include temperature computation, while the effect of IOR chemicals are often critically dependent on temperature. We have therefore implemented the temperature equation in IORSim as an option. The temperature computation has been verified against the Eclipse temperature computation.

A SAMPLE RESULT

Figure 2 shows an example of how ion concentrations (Mg, SO4) are sensitive to temperature. These concentrations are crucial for flow properties as for instance relative permeability. The figure shows concentrations with fixed initial temperature and computed temperature, respectively.

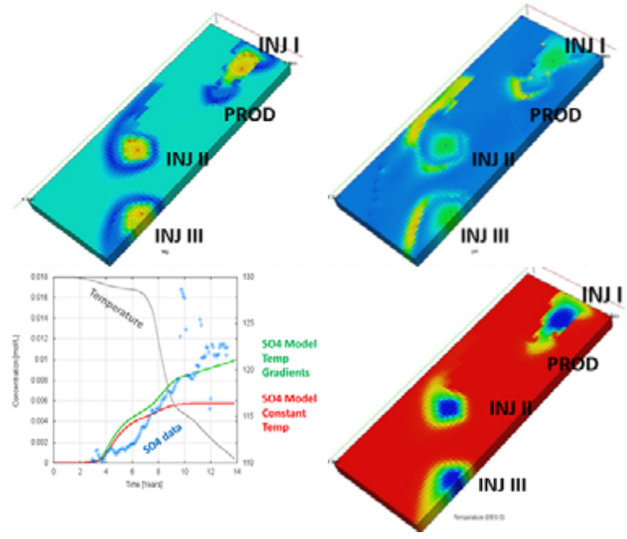


Figure 2: (Top left) Magnesium concentration in reservoir, (Top right) reservoir pH – blue colour ~6.5 and yellow ~9. (Bottom left) Produced sulphate concentration in producer compared with well data. The red line shows the results when IORSim is run with constant (high) temperature and green line takes into account the temperature front induced by the cold water. (Bottom right) Simulated reservoir temperature gradients.

UNDERSTANDING THE EOR MECHANISMS

- IMPLEMENTING NEW METHODS

BY UDO ZIMMERMANN AND PHD MONA MINDE

During 2015 Task 2 had the opportunity to utilize a wide range of methodologies to study chemically altered rocks due to EOR experiments. Some of the methods are XRD, Focused Ion Beam Scanning Electron Microscopy (FIB-SEM), Field Emission gun Scanning Electron Microscope (FEG-SEM) and a Transmission Electron Microscope (TEM) which offer magnifications over 100 000 times on samples of both geological and material science background (Figure 1). This is of great importance when studying alterations due to EOR processes, both in regards to textural and chemical alterations. By the use of TEM it is possible to image materials down to the atom (Ångstrøm)-level and we have successfully mapped the mineralogy of flooded chalk on grain-scale by the use of TEM together with Energy dispersive spectroscopy (EDS) and diffraction patterns reflected by the crystal lattice of each mineral (Figure 1 b).

Figure 1; a) TEM BF-image of flooded chalk. Red dot shows area where the diffrection pattern (b) is taken from. The white pattern in b) reflects the crystsal lattice of calcite

Many tools used to study rocks at nano- and micron-scale are tools typically used by material science and this offers a great opportunity to learn from other disciplines and to further improve the high quality cross-disciplinary cooperation we have at UiS.

Imaging at high resolution has given us further insight on the dissolution and precipitation of minerals; what type of processes and where they preferentially take place. Well defined crystals of high magnesium bearing carbonates have been imaged (Figure 2). The use of Cryo-SEM, where samples are frozen by liquid nitrogen, enables imaging of samples containing fluids (Figure 3) where we can amongst others study pore-fluid distribution.

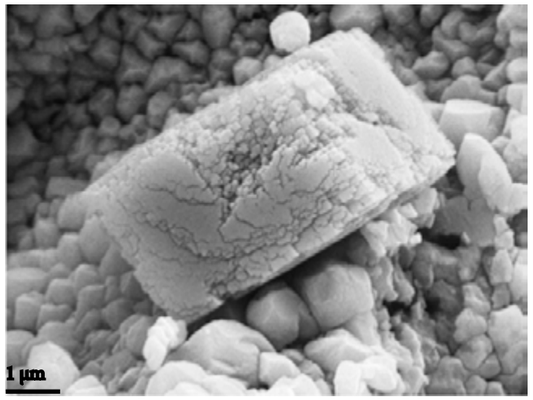


Figure 2; SEM micrograph of precipitated carbonate with high magnesium content

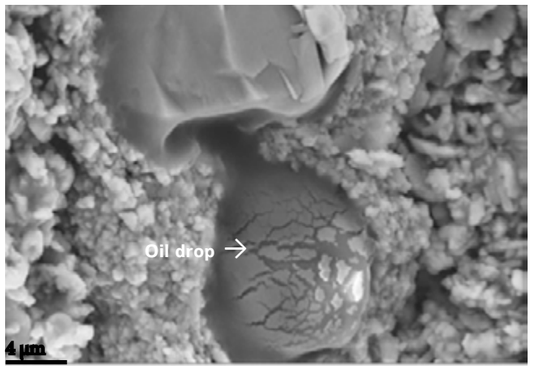


Figure 3; Image of oil in chalk-pore made by the use of Cryo-SEM

We have worked intensely to incorporate "new" methods into our toolbox and through the use of Mineral Liberation Analyses (MLA) mapped alterations and texture of rock samples at micron-scale (Figure 4), and elemental mapping at nanoscale by nano secondary ion mass spectroscopy (nano-SIMS) (Figure 5).

In Milan we could use a microRaman and established a semi-quantitative relation-ship between raman-shift in carbonates and Mg-concentration (submitted manuscript). This allows us to estimate Mg-abundance in flooded chalk samples with a quick and cheap method, compared to many electron- or ion-beam based analytical technique. During the spring of 2016 we will commence a collaboration with the École Polytechnique de Paris, where we will use nanoRaman technology coupled with atomic force microscopy (AFM) to further develop this technique allowing us to identify newly formed minerals with different Mg-content in flooded rock samples.

This leads us to be close to one major objective of providing a tool kit for the analysis of flooded rock material for the purpose of determination of mineralogical and chemical changes.

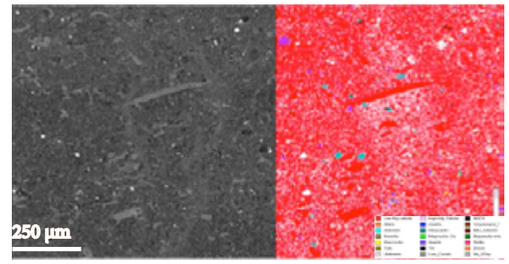


Figure 4; Fig 3: Back-scattered Electrons-Scanning Electron Microscopy (BSE-SEM) micrograph (a) and Mineral Liberation Analyses (MLA) image (b) showing how a fragment of macrofossil influences the fluid-flow, perpendicular to shell, in fractured Liège chalk flooded with MgCl2

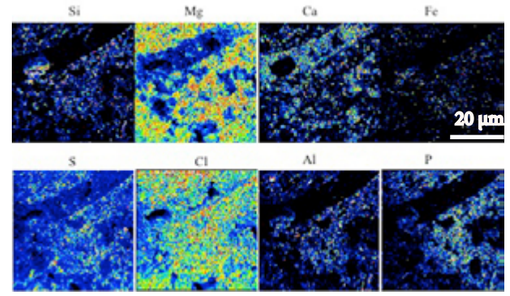


Figure 5; NanoSIMS mapping of different elements at the same area showing relative concentrations of elements in and outside a shell-fragments in chalk matrix

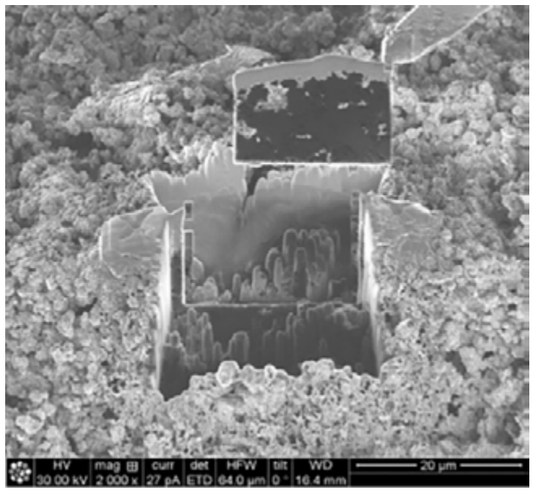


Figure 6; Focused Ion Beam Scanning Electron Microscopy (FIB-SEM) lift-out of lamella for Transmission Electron Microscope (TEM) analyses.

RESERVOIR SIMULATION TOOLS

BY OVE SÆVAREID

> "The reservoir simulator development in OPM serves as a unique testbed for implementing new methods. We are already exploring these opportunities both for EOR methods and for novel approaches to numerical methods in reservoir simulation. Hopefully, these efforts will lead to accelerated development of reservoir simulators in general."
>
> Alf Birger Rustad, Statoil

OPM (Open Porous Media, http://opm-project.org) is an open source framework for reservoir simulation. Commercial reservoir simulators have two major drawbacks – licenses are expensive, and the process of obtaining acceptance for added/improved functionality is at best long and tedious. Direct access to source code offers the possibility to tailor-make simulation capabilities according to specialized needs. The concept of challenging expensive, closed source, commercial simulation tools with open access frameworks like OPM is a catalyst for innovation, both technically and commercially. Also, open source code has great potential for educational use.

Through The National IOR Centre, IRIS has significant activity related to OPM, and sees OPM as a long term strategic commitment. Research results presented in terms of publicly available source code is a valuable supplement to traditional publications and promotes reproducible computational science. The framework serves as an in-house simulation and research tool, it is a vehicle for national and international cooperation and synergies across institutions, and it attracts R&D activity related to enhancing and expanding the code functionality.

During 2015 task 6 activities have contributed to improved functionality and performance of the OPM black oil simulator; e.g. additional relative permeability models, solvent functionality, improved solvers and parallelization. Versions 2015.4 and 2015.10 of the framework have been released. Tests of the OPM black oil model and polymer model on scales relevant for a detailed single well model were performed. Higher order, fully implicit numerical schemes for polymer flooding (postdoc), have been investigated in preparation for future simulator improvements.

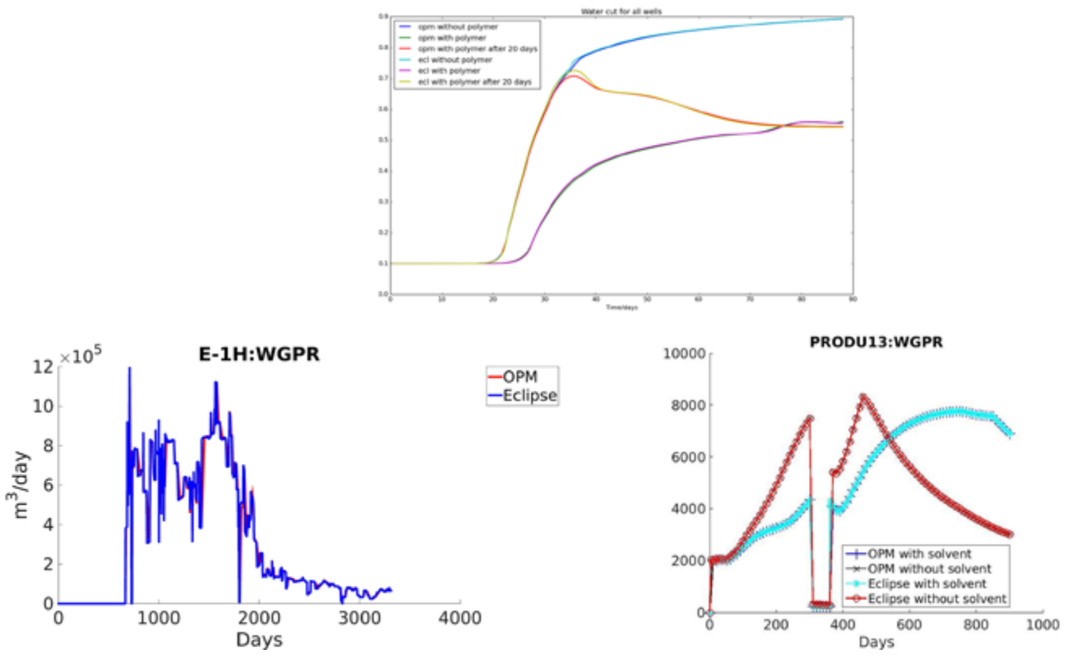


Figure: Comparing OPM and Eclipse. Left to right: Norne field benchmark, polymer modelling and solvent functionality.

SMART WATER FOR EOR BY MEMBRANES

ONE OF THE PHD PROJECTS IN THE CENTRE

BY PHD REMYA NAIR

The goal is to minimize footprint, operating costs and maximize energy efficiency while upholding oil recovery.

Theme 1, Task 4 at The National IOR Centre deals with production of smart water by membranes. The research makes use of membrane desalination processes in a unique configuration to arrange for water streams of required ionic strength. The research seeks to optimize the overall water injection process for EOR.

Increasing cost for exploring, and developing new oil reserves, decreasing production from mature reservoirs, strict environmental regulations for management of produced water (PW) necessities EOR project development. Novel technologies for water treatment are used to create specialised injection brine compositions. Injection water with selective ionic composition is a requirement for smart water flooding in carbonate reservoirs. Smart water enriched in divalent ions such as Ca^{2+}, Mg^{2+}, SO_4^{2-} together with decreased concentrations of monovalent ions Na^+ and Cl^-, is necessary for optimum oil recovery in carbonate reservoirs.

The aim of this research is to develop a novel, environmentally focused and reliable method for smart water production capable of functioning in a challenging environment. The goal is to minimize footprint, operating cost and maximise energy efficiency while upholding oil recovery. Membrane experiments were performed to verify whether seawater and oil free Produced Water (PW) may be treated and used as smart water in carbonate reservoirs.

Recent research suggests that low salinity water has the ability to increase oil recovery. Numerous testing has been undertaken internationally to further develop this concept. In low salinity water flooding, either fresh water or desalinated seawater is used. Desalination costs depend on aspects such as pre- and post-treatment, designated technology, feed water quality and quantity, plant location, energy availability and disposal of brine. Two different technologies for desalinating seawater are thermal distillation and membrane separation.

Membranes for smart water

My membrane experiments are using two types of membranes, reverse osmosis (RO) and nanofiltration (NF). Both work on similar principle as regular particle filtration, where distinguishing feature differentiating the two is their effective pore size and, accordingly, the minimum size of particles that will be rejected by the membranes. RO is a much tighter membrane with pore size around 0.0005 micron, and rejects all particles except water molecules from seawater with a particle rejection efficiency > 99 %. Hence, the product water or permeate is potable with salts < 500 mg/L. NF is looser than RO with pore sizes from 0.05 to 0.005 micron. NF rejects organic molecules, sugars, and multivalent ions, with only monovalent ions and water passing through the membrane.
Using RO for desalination required smart water composition is obtained by adding chemicals to RO permeate. By using NF, smart water is attained from the retentate, enriched in divalent ions with no chemicals added.

Acceptable water quality and quantity for enhancing oil pro-

duction vary between reservoirs. Whether it is technically and economically possible to accomplish proper water quality is evaluated in each case. In this research, volume of water used for injection by Marathon Oil at The Brae Alpha field is model for calculations. Brae Alpha field uses 20,000 bpd (barrels per day) or 108 m^3/h of water. The optimal technique for smart water production is chosen by estimating power consumed by each.

Fresh water from land (6.94 KWh/m^3) is an economical process. However, due to the socio-environmental aspects and often lack of available fresh water, NF can be chosen as the most viable process in terms of energy consumption (47.5 KWh/m^3) and with no chemicals added. Because NF has larger pores than RO membranes, NF has higher flow rates and thus requires less number of membrane elements with a significant reduction in footprint and costs. NF also requires less pre-treatment compared to RO. The energy consumed by RO (1100 KWh/m^3) can be decreased 50 % by high-pressure energy recovery. Multi Stage Flash Distillation (MSFD) is power intensive, 1500 KWh/m^3, making it the least economical option.

Experiments for bridging membranes with EOR applications

Experiments with membranes were done at University of Stavanger. We have excellent and productive collaboration with membrane producing companies such as Dow Chemical/ Filmtec and Hydranautics who supplied membrane elements for the experiments.

Three different types of NF membranes have been tested. Both seawater and synthetic PW are used as feed to the membranes. Seawater was filtered prior to membranes to avoid fouling, plugging and bacterial growth. Produced water quality varies significantly depending on the properties of the reservoir, in terms of hydrocarbon content, dissolved solids and

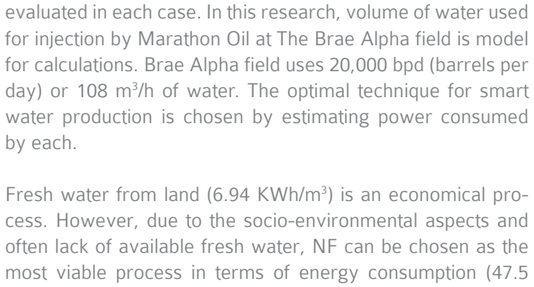


Figure 1. Increased permeation of Cl^- when SO_4^{2-} is spiked in feed water

other contaminants. Oil free synthetic PW is tested to remove scaling ions such as barium.

Both permeate and reject streams from NF can be used when seawater is used as feed; retentate flow for smart water and low total dissolved solids (TDS) permeate flow with further treatment for potable water production.

The following results were obtained from the experiments:

• Effective separation of divalent ions from seawater resulted with NF membranes. 99 % SO_4^{2-}, 80-85 % Mg^{2+} and 50- 60 % Ca^{2+} were retained in the divalent stream.

• Smart water for EOR requires two to three times increased concentration of SO_4^{2-} compared with seawater. When sulphate is spiked in seawater as feed for NF membranes, a decrease in Cl^- were observed and is shown in Figure 1.

• 81% of barium present in PW are retained during NF experiments and other permeated divalent ions may be used efficiently for smart water production.

• Main obstacle encountered in my research is comparatively high concentration of monovalent ions in the retentate stream. Now the goal is to manipulate the membranes to permeate more Na^+ and Cl^-.

• NF performs partial desalination at low pressure, resulting in higher flux and recovery. However, in order to attain the high quantity of water required for injection, NF treated de-oiled PW should be mixed with NF seawater retentate. Figure 2 illustrates the proposed combination for PW reinjection as smart water. Seawater can also be directly mixed with NF treated PW. But this will result in undesired increase in monovalent ion concentration which may adversely affect the smart water efficiency. The ratio between mixing PW and seawater depends on initial TDS and barium concentrations of PW, daily PW volume, precipitation stage efficiency and desired injection flow.

Results from my experiments can be used to optimize water treatment technology with new designs, and facilitate EOR projects. NF produces smart water and is favorable in terms of space and weight requirements as well as energy and environmental costs. No chemicals are added during smart water production. The results from the experiments is one-step closer to our aim, "Recover for the Future"

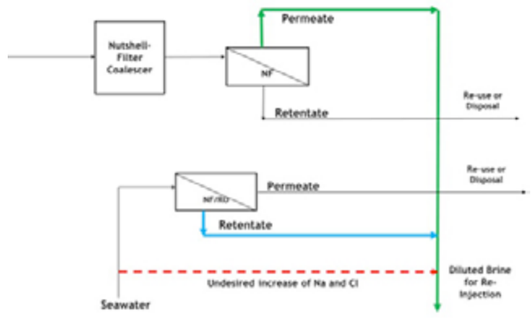


Figure 2. Options for adjustments of ionic composition of smart water from treated Produced Water (PW).

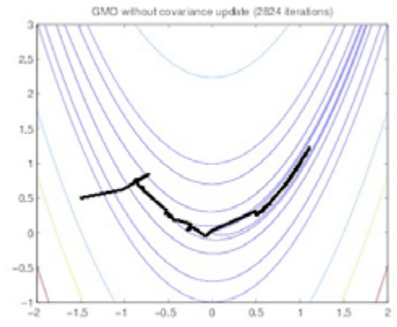
GRADIENT FREE OPTIMIZATION UNDER UNCERTAINTY

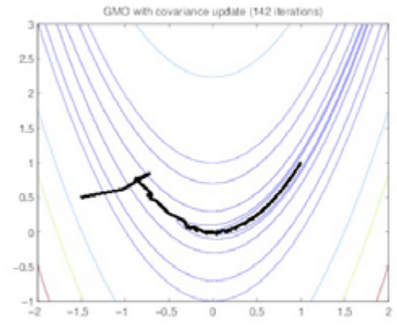
BY ANDREAS STORDAL AND GEIR NÆVDAL

STUDY BY ANDREAS STORDAL IN COLLABORATION WITH DUTCH RESEARCHERS

The plans for future production will usually be based on reservoir simulations. A strategy is sought that maximizes the Net-Present-Value (NPV) or the total oil production of the reservoir. This can be formulated mathematically as solving a multidimensional optimization problem, max J(x). If one has access to gradients, these will be utilized, but for most reservoir simulators the required gradients are not available. This means that methods to develop efficient approximations of the gradients will be of great interest. Since each run of the reservoir simulator is usually quite time consuming, efficient methods for solving this problem is of great benefit.

A Monte-Carlo approach for finding the vector that maximizes J(x) is developed. The idea is to sample a set of candidate steps from a Gaussian density function, which is defined by its mean and covariance matrix, and use these samples to calculate an approximate gradient. A calculation approach can be defined with nice theoretical properties, but for optimizing on a single reservoir model the efficiency is far from what can be achieved with a gradient-based approach. The ideas followed here, are close to those developed as a natural evolutionary strategy known as Gaussian Mutation. In the research done by Andreas Stordal, IRIS, together with Slawomir P. Sklarz, Delft University of Technology, and Olwijn Leeuwenburgh, TNO,





"The key element of success for an asset, both in exploration phase or redevelopment, is optimizing the field development plans. In order to this, to have an optimization tool (workflow) is a must.

Another key element of success is to move away from the base case philosophy towards the multiple realizations approach (quantifying uncertainty)

The work done by The National IOR Centre of Norway on the "Gradient free optimization under uncertainty" is very important because it falls in the heart of all the above mentioned areas of research. It is a requirement to keep track and develop methods that will allow us to optimize our field production (short and long term) tacking into account the geological uncertainties.

We are continuously and very successfully collaborating with The National IOR Centre of Norway on the optimization area of research and we find their contributions of high value."

Remus Hanea, Statoil
Specialist Res Tech

(Mathematical Geosciences, 2015), it was demonstrated that both the mean and covariance matrix of the Gaussian density function was updated, as opposed to previous work, where only the mean was updated, a much more efficient algorithm was developed. For a well-known test case, optimizing the Rosenbrock function. $f(x,y)=(1-x)^2+100(y-x)^2$, one could solve the problem using 142 iterations instead of 2842 iterations. See the two figures.

Another important finding of the research is that efficient methodology for optimizing over a set of reservoir models can be developed along these lines. Since our knowledge about the reservoir is uncertain, it is natural to account for this uncertainty by optimizing the future production over a set of reservoir models instead of a single model. In the case where one works with several models, the Monte-Carlo approach can be made close to a gradient based approach in efficiency as well since one can evaluate different strategies for each of the reservoir models.

The results obtained in this research were judged so promising that Statoil funded an additional project in 2015 to do further testing on reservoir models, which gave further confirmation of the practical value to the theoretical work that one started out with.

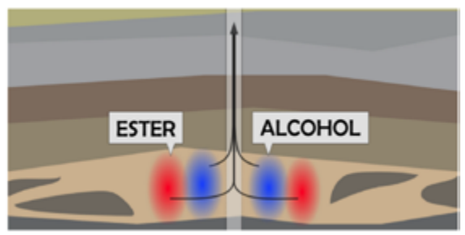
REACTIVE LANTHANIDE CHELATES FOR SINGLE-WELL CHEMICAL TRACER TESTS

BY TOR BJØRNSTAD

THE IDEA

Single-Well Chemical Tracer Tests (SWCTT) are routinely used by the oil industry to determine the residual oil saturation (S_{OR}) in the near-well zone. Today's tests use reactive esters such as ethyl acetate as reactive traceers. During a SWCTT, ester is injected into the formation. Parts of the ester react with water (hydrolysis) to form alcohol (and acid). During back-production (see illustration) the water-oil partitioning ester lags behind the alcohol which is a pure water tracer. The time-difference between the two compounds is directly related to oil saturation in the formation.

Despite their efficiency in determining S_{OR}, these tracers suffer from a high detection limit. Hundreds of kilograms of tracers

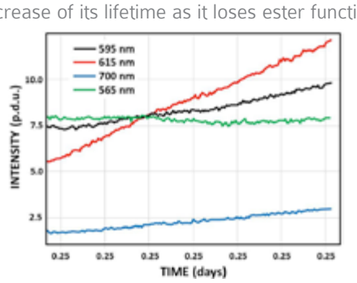


have to be injected into the formation to allow their detection. This project aims at creating new tracers that can be detected at low concentration using fluorescence. This would considerably reduce the operation costs of the test and permit an on-site or even online detection of the tracers, which would lead to faster and more reliable results.

WORK PERFORMED IN 2015

The first part of 2015 was focused on establishing a proof of concept for our tracers and the way they should be detected. Multi-ester lanthanide chelates were synthesized from DTPA (diethylenetriaminepentaacetic acid), mass spectroscopy revealed the presence of mono-, di-, tri-, tetra- and penta-ester in the different batches with a large prevalence of penta-ester. The light (or laser) induced luminescence of these chelates associated with europium was measured using time-resolved spectroscopy.

The results reveal a progressive change in the intensity of the emission peak of the result complex as the various ester functions hydrolyse over time. We can observe that the intensity of the peak at 615 nm becomes greater than the peak at 595 nm after roughly 18h. Meanwhile we can also observe that the overall intensity of all peaks increases. These changes reflect both an increase in the quantum yield of the complex and an increase of its lifetime as it loses ester functions. This



behaviour of the luminescence make it possible to detect and quantify both the ester version and the acid version of this lanthanide chelate using luminescence.

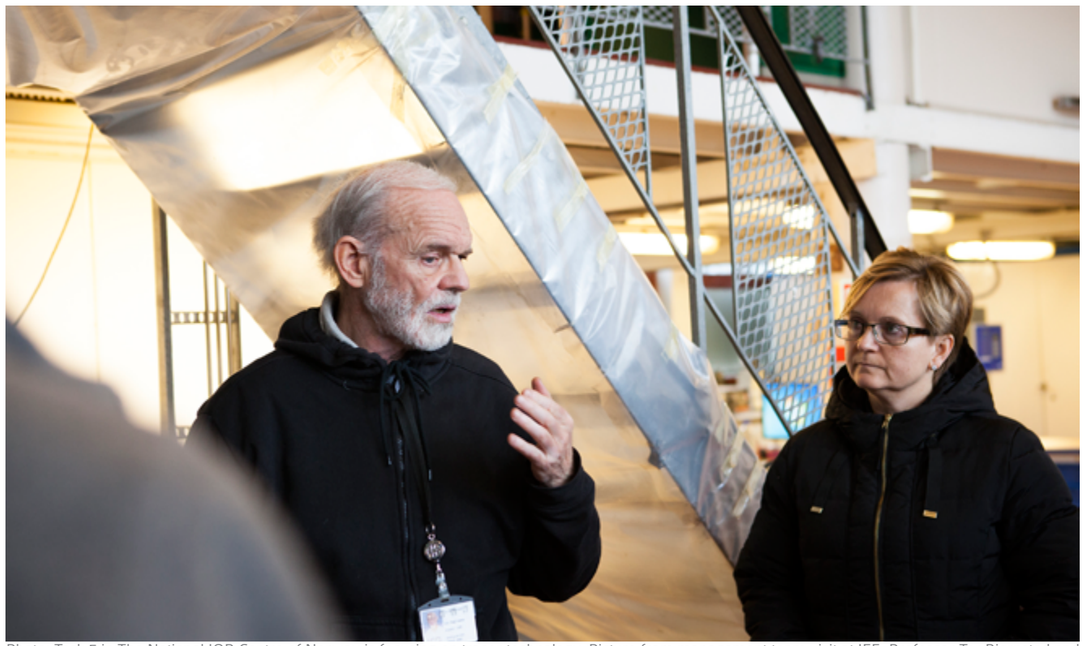
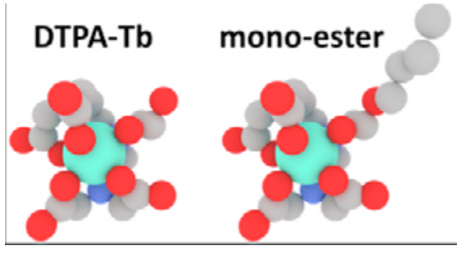


Photo: Task 5 in The National IOR Centre of Norway is focusing on tracer technology. Picture from management team visit at IFE. Professor Tor Bjørnstad and Iren Lobekk

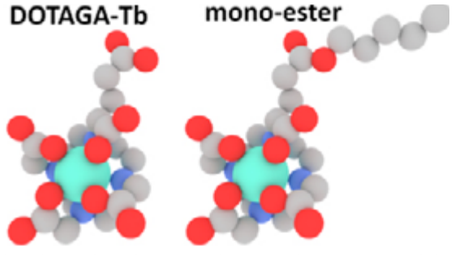
THE TECHNICAL DETAILS:
DOTA = 1,4,7,10-TETRAAZACYCLODODECANE-1,4,7,10-TETRAACETIC ACID
DOTAGA = 1,4,7,10-TETRAAZACYCLODODECECANE,1-(GLUTARIC ACID)-4,7,10-TRIACETIC ACID
DTPA = DIETHYLENETRIAMINEPENTAACETIC ACID
DTPA-BA = DTPA-COMPLEX WITH BARIUM

Numerous syntheses were performed in 2015 to produce mono-ester chelates in reasonable quantities. Mono-ester



are preferable to multi-ester chelates as only two compounds would be recovered, one partitioning and one passive. New synthesis routes were found using milder methods based on the use of DTPA-BA and DOTAGA anhydride. We have confirmed using mass spectroscopy, the synthesis of three different DTPA mono-ester chelates with different ester chain length.

We also can confirm the synthesis of one DOTAG mono-ester. Our work in 2015 also focused on the separation of reaction products from both reagents and unwanted by-products. A



method has been found to provide a good separation of the acid and ester versions of the chelates. Our work in early 2016 will focus on the production of sufficient quantities of ester chelates, well purified and isolated. This will allow us to move on to their full characterization, which will include luminescence, partition coefficient and transport properties.

ESTIMATION OF RESERVOIR PARAMETER CHANGES USING TIME-LAPSE SEISMIC DATA FOR COMPACTING RESERVOIR

BY TUHIN BHAKTA

All kinds of effects are visible in the 4D seismic data of the Ekofisk Field, such as effects of changes in saturations, porosity, pore-pressure, salinity etc. The compaction of this chalk field complicates the interpretation of the changes in the seismic data obtained at different times. Therefore, the most necessary action is to quantify the changes in the reservoir parameters that have direct impact on production performances. Time-lapse Amplitude Variation with Offset (AVO) could serve this purpose.

The AVO inversion method we are using is a direct inversion scheme based on first order or second order approximations of the analytical expression of pressure, saturation, porosity changes as a function of reflectivity coefficients. The method relies on the fact that the variations in dynamic properties (pore-pressure, saturation, porosity) of the reservoir are detectable from the changes in intercept and slope of the AVO response for the reservoir reflector; using various partial stacks of the baseline and the monitor surveys (Landrø, 2001). However, this conventional AVO method under or over predicts the reservoir parameter changes. In addition, the estimates suffer leakage among them. The main reasons are improper approximation of rock physics parameters in case of nonlinear relations among seismic parameter changes and changes in reservoir parameters; and error due to first order

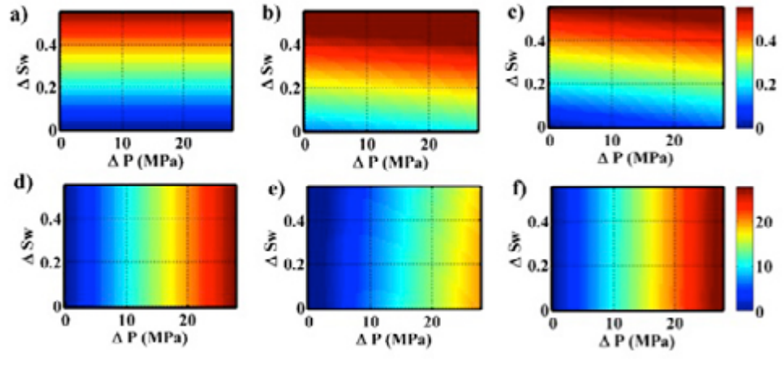


Figure 1: For compacting chalk reservoir: real changes in water saturation (a) versus changes in water saturation estimated with the conventional AVO method (b) and new method (c). Panels d, e and f are the real and estimated pressure changes, in similar order as in panels a, b and c. Colorbar of each figure represents the values of either saturation or pressure changes.

"THE NEXT STEP IS TO IMPLEMENT THE METHOD IN REAL FIELD CASE."

"The task of planning infill drilling in a mature field sets especially high requirements with respect to the precision of well targets, well trajectories and production forecasting. The use of 4D seismic has proven to be a valuable resource for managing decisions by reducing uncertainty or variability of simulation models. The suggested 4D AVO analysis and attributes will add an additional source of information for discriminating fluids (gas, oil and water) in the reservoir. This analysis can provide us with the critical information on water front movement and free gas presence in the reservoir."

Evgeny Tolstukhin, Sr Reservoir Engineer
ConocoPhillips Norway

approximation in changes in gradient and intercept attributes. We address both the problems by implementing a non-linear optimization method (the Levenberg-Marquardt (LM) method) to estimate the changes using AVO equation directly (Bhakta, 2015). To demonstrate the applicability of the new non-linear optimization method we test the method for a synthetic compacting reservoir case. Figure 1.a shows real change in water saturation, whereas Figure 1.b and c show the estimated water saturation using the conventional and new non-linear methods (LM method), respectively. Similarly, Figure 1.d-f show the real and estimated pressure changes with different methods, in similar order same as in Figure 1.a-c. Observe that the conventional method over-predicts water saturation changes and under-predicts pressure changes. On the other hand, the non-linear LM method provides better estimates of both the changes than the conventional method.

The next step is to implement the method in real field case. To perform the planned research, we have received partial stacks data (AVO data) from the Ekofisk field. These are data obtained using the Permanent Reservoir Monitoring (PRM) system installed at the Ekofisk field in 2010. Before exploiting these AVO responses of different vintages, it is necessary to correct for other data artefacts/ differences while effectively preserving all production/ injection related reservoir changes. We use the Non-Rigid Matching (NRM) technology of Schlumberger for this 4D calibration purpose. These 4D calibrated partial AVO stacks for various years would be then used for estimating the reservoir property changes.

This work is a part of the longer-term goals of better usage of time-lapse seismic data to monitor dynamic reservoir parameter changes. This will be of particular benefit for those reservoirs, as Ekofisk, which is equipped with permanent reservoir monitoring systems. Further, to better utilize the estimated reservoir parameters in the history matching workflow based on ensemble methods developed in other projects of The IOR Centre, a special focus is paid to quantify the associated uncertainties in the estimates.

The main benefit of this research is to improve understanding of the remaining hydrocarbon compartments; thus helping in infill drilling. By doing this one can take full advantage of high repeatability of PRM data. It will also be of great benefit if we can use the data to support better reservoir characterization and management by providing reservoir simulation models that account for the information in the 4D seismic data.

PERMEABILITY AND POROSITY DURING CHEMICAL TRANSFORMATION AND MECHANICAL COMPACTION

BY ANDERS NERMOEN

What happens if you compress a porous chalk while flowing a reactive fluid until the chemical reactions come to a completion? The world longest lasting tri-axial cell compaction experiment was performed by Reidar I. Korsnes and Anders Nermoen and led by Merete V. Madland at the Geomechanical laboratories at University of Stavanger.

1092 DAYS. This is, to our knowledge, the longest lasting tri-axial cell experiment that has been performed in the world ever, says Reidar I. Korsnes. In order to better understand the physio-chemical processes in chalk reservoirs during seawater injected over relevant time spans, a wide range of experimental approaches are required. Without experimental observations in controlled environments, it is nearly impossible to imagine the dynamical transformations that could occur. Reservoir cores are sparse and highly valuable. To explore the interesting nature of how the injected fluid composition affects immiscible flow dynamics, mechanical properties and mineralogical alterations in reservoirs, analogue outcrop core material are required.

THE TEST. A chalk core extracted from a quarry outside of Liège in Belgium was mounted into a tri-axial cell and flooded with $MgCl_2$ brine at 130°C. Liege chalk is a mudstone of late Campanian age consisting of more than 90-95% calcium carbonate ($CaCO_3$), while the non-carbonate phases are quartz, smectite, mica and other trace minerals. Previous studies have shown that different ions in the injected water react with the mineral surfaces leading to measurable changes in the oil recovery, mechanical stability and mineralogical composition. During flow, the core was compressed hydrostatically (i.e. same stress in all directions) while we monitored the external size of the core, the permeability and the ion composition of the fluids exiting the core. We wanted to study how compaction and flow affect permeability? What happens to the mineralogy? How will the flow affect the compaction rate? What happens to porosity?

CHANGES IN THE FLUID COMPOSITION. The aggregated sum of chemical reactions within the core can be dynamically monitored by quantifying the ion concentrations of the effluent fluids exiting the core. The ion concentration of magnesium, calcium and chloride are measured through time. We

observe that the magnesium concentration is reduced due to precipitation of Mg-bearing mineral phases, while calcium is

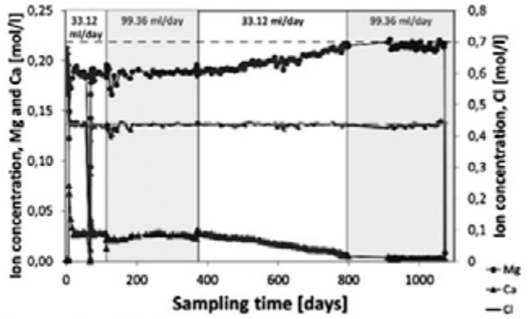


Figure 1. Chemical composition of the fluids exiting the core trough time. Calcium ions are produced from dissolution, and magnesium ions are lost due to precipitation. The chloride ion concentration is almost un-changed.

produced indicating dissolution of the calcite, Figure 1. At the same time, the chloride concentration is almost unchanged which indicates that this ion is not significantly involved in any chemical reactions. As can also be seen, the chemical reaction is reduced with time. By integrating up the produced calcium, we find that more than 98% of the original calcium that was in the core before the experiment started were dissolved. As has been shown by several other authors, and also confirmed here, the flow of magnesium chloride leads to the formation of magnesite and dolomite. These mineral phases have a higher density than calcium carbonate. This effect, in addition to a significant mass loss, has shown to reduce the total mineral volume within the core.

CHANGES IN MICROSCOPIC MORPHOLOGY. When minerals dissolve and secondary minerals precipitate, the microscopic morphology of the grains constituting the porous material are subject to changes. These changes can be seen in Figure 2 in which a SEM image of an un-reacted end-piece of the core is shown in the upper pane. After the core was dismantled SEM images were also acquired. These images display a remarkable change in the microscopic morphology. Typically, the precipitated minerals display a more rhombohedral angular shape and their size is smaller than the grains in the original core. The reduced size leads to higher specific surface area, since the volume to surface ratio is inversely dependent upon size.

VOLUME CHANGES. During the presented experiment, the volumes that constitute the porous material were all subject to changes. Overall, the total volume evolution, as shown by the volumetric creep (solid line) in Figure 3, is reduced with time, and because of the negative second derivative the rate of creep is also reduced with time. In addition to that, an important observation can be made: The creep rate is affected by the flow rate. At 112 days the flow rate was trebled which lead to more chemical reactions in the core (since the concentrations of the produced calcium and retained magnesium were almost the same, see Figure 1). The pattern was reproduced at 368 days when the flow rate was reduced and at 777 days when it was increased again. Now, the solid volume is always given by the mass divided by the density. Using He-gas pycnometry, we found that the density changed from 2.69 g/cm^3 initially to 2.90 g/cm^3 after the test, and that the mass was reduced from 125 g initially to 102 g. As such, the solid volume reduced from 46 to 35 cm^3. Since we measure the total volume and estimated the solid volume (using the IC-analysis) we could calculate the pore volume and plot the porosity as function of time in Figure 3. When doing that, a remarkable dynamics can be seen: Initially the porosity was 42%, and when compaction dominated the overall process the porosity reduced to a minimum of 33% after approx. 200 days. From 200 days and onwards, the rate of chemical reactions were more important to the overall volume changes than compaction, such that the porosity increased to more than 40% again after 1000 days. During the last 100 days, or so, the porosity reduced again, since the chemical reactions terminated (there were no more calcium carbonate to react with!), and the compaction became more dominant.

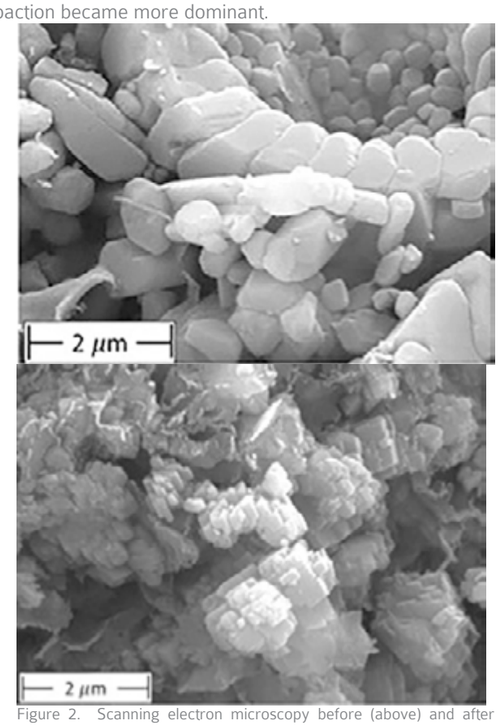


Figure 2. Scanning electron microscopy before (above) and after (below) the flooding experiment was conducted.

PERMEABILITY CHANGES. During compaction and flow, the hydraulic one phase permeability was monitored with time (solid line in Figure 4). The observed permeability shows a similar dynamics as the porosity (dotted line). When compaction dominates the overall process during the first 200 days, the permeability is reduced by almost a factor of 10. However, as chemical reactions become increasingly important, we observed that the permeability increased with time. Until 400 days, the permeability observations are in-line with the estimated porosity evolution. From 400 days and onward, the permeability remains the same even though the porosity increased with time. The discrepancy between the observed permeability and porosity evolution from 400 days could be understood by considering changes in the specific surface area changing from 3-4 m^2/g originally to 8-9 m^2/g afterwards. The changes in the specific surface area are in line with the SEM-images in Figure 2 where the precipitated grains are smaller than original.

IMPLICATIONS. Even though being highly non-intuitive it is possible to understand the changes in both porosity and permeability when chalks are exposed to chemo-mechanical

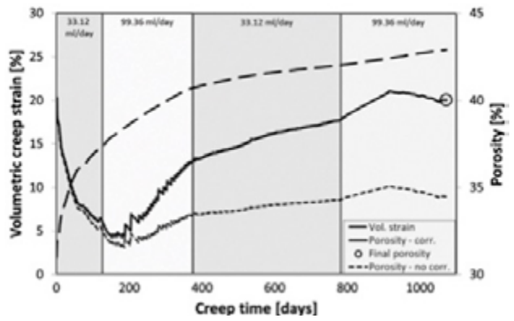


Figure 3. Volumetric creep observed through time (dashed line). The dynamic porosity has been calculated from the total volume and the solid volume with time. The solid volume is calculated from the effluent ion composition and the changes in average mineral density. Solid circle represent the porosity measurement after the experiment was dismantled.

processes. The key in this case was to acknowledge that the pore volume, solid volume and total volume are all subject to change. The discrepancy between the measured permeability and the observed porosity can be explained by the precipitation of secondary minerals (that each grow in time) leading to significant changes in the specific surface area.

When injecting seawater into chalk reservoirs, similar chemical reactions most probably take place as the Mg-ion in the seawater lead to precipitation of Mg-bearing minerals and dissolution of calcium carbonate and/or silicates originally present in the chalk. These (and other) chemical reactions are important to the mechanical stability of the chalk framework and to absolute permeability over time. The implications to reservoir systems can be detrimental when considering the rate at which fluids can be injected at the injector side (with a given pressure), well failure and seafloor subsidence, which will also affect the equipment resting on the sea floor. However, the physio-chemical interplay may have beneficial consequences since the compaction drives the residence fluids towards the production facilities, the local permeability reduction leads to natural water divergence and the chemical reactions change the way in which hydrocarbons are bond to mineral surfaces, an important aspect of immiscible flow dynamics.

For further reading see the reference:
Porosity and permeability development in compacting chalks during flooding of non-equilibrium brines: Insights from long-term experiment. Geophysical Research: Solid Earth (2015) by Anders Nermoen, Reidar I. Korsnes, Aksel Hiorth and Merete V. Madland, doi: 10.1002/2014JB011631

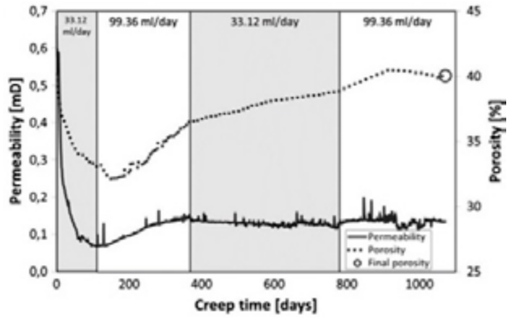
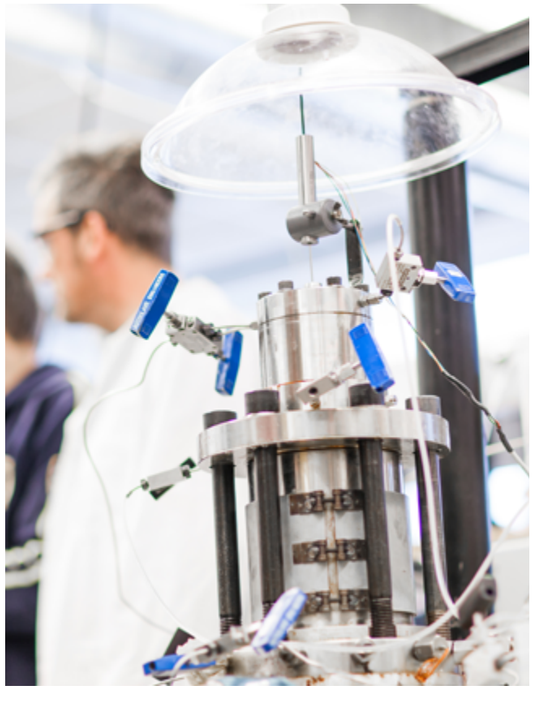


Figure 4. The measured hydraulic permeability (solid line) and the estimated porosity (dots) plotted through time.



LARGE SCALE TEST ON POLYMER DEGRADATION

The National IOR Centre of Norway and Halliburton invited members of the technical committee to a site visit at IRIS on the occation of the polymer shear test that was executed at the UBBS (Ullrigg Drilling and Well Centre) facility at IRIS.

"One of the key challenges related to offshore field implementation of polymer flooding is the risk of shear degradation of synthetic polymers in topside equipment such as chokes, valves and pumps. These challenges are more difficult to control in an offshore setting, where space and weight limitations might exclude complex equipment, and subsea wells will require individual chokes for each well.

The mechanism of shear degradation can be studied in detail in the laboratory, but it is essential to test and verify the results in real systems using realistic dimensions and rates. A yard tests is a very useful step in the technology development of synthetic polymers for offshore use. It can close the gap between laboratory and pilot or full scale testing. In a relatively cheap way key technology elements can be tested in full or near full scale. Lab scale results can be verified, allowing the development to proceed to pilot or full scale testing."

– Knut Uleberg, Statoil

A large scale polymer degradation test was this autumn successfully performed by Halliburton at the IRIS test facilities in Stavanger.

Polymer flooding is one of the more promising EOR methods. The most frequently used EOR polymers are the high molecular weight (HPAM) based polymers which however are known to be sensitive to shear degradation. It is therefore critical to be able to quantify the extent of degradation these polymers may undergo, under realistic conditions. It is also highly desirable to investigate any mitigation actions that may potentially minimize degradation.

The test program included two different polymers; high molecular weight HPAM polymer (FP 3630 supplied by SNF) which is regarded as the reference EOR polymer and a low molecular weight AMPS co-polymer (AN125, also supplied by SNF). AN125 was considered, from previous work, to be less shear sensitive. The polymers were tested in following four different choke valves:

1. Halliburton Standard adjustable choke valve, Type CH2M choke. (Choke 1)
2. Matek choke valve type 3254-7 (Choke 2)
3. SNF Linear pressure reducer, LPR, (Choke 3)

Tests were also performed on Halliburton Fixed choke valve - Orifice with fixed ID of 20/64" (Choke 4) and 24/64" (Choke 5). Prior to testing the general understanding was that the SNF Linear Pressure Reducer, LPR, which consists of a long coiled tube would be superior to the other choke types. Further on, it was assumed that the low molecular weight AN125 polymer would behave better than the high molecular weight 3630polymer. As expected, test results with Choke 3 and polymer 3630 at 40 bar pressure drop over 400-600 meter showed viscosity loss of only 6.6%. The viscosity loss from a corresponding test with Choke 1 was 76%.

The Matek choke (Choke 2) was found to perform slightly worse than Choke type 1. The Matek choke degraded the 1000 ppm 3630 polymer 82% while Choke 1 degraded the same polymer to 76%. For 1000 ppm AN125 polymer and Matek choke, the degradation was 73%. The corresponding test with Choke 1 resulted in 69% degradation. The effect of the polymer concentration on polymer degradation was evident. In Choke 1, the 3630 polymer was degraded by 76% at concentration of 1000 ppm and by 66% at 2000 ppm. The AN125 polymer was degraded 69% and 64%, respectively. However, when increasing the 3630 polymer concentration to 10000 ppm, the polymer degradation was reduced to less than 10%.

Tests, with multiple choke valves rigged in series to evaluate the effect of stepwise choking revealed that multiple small step choking is better than a single large step choking. In one test using three serially mounted chokes at differential pressure of 15, 15 and 25 bar, resulted in similar degradation as in a single choke test with 55 bar pressure drop. However, when the differential pressures were lowered to 5, 5, and 5 bar for each choke, the total degradation was significantly better than the degradation from a single choke test with 15 bar pressure drop. We conclude that standard choke valves at differential pressure up to 50 bar will severely degrade synthetic polymers. This test addressed the following three possible methods to reduce the polymer degradation:

- Reduce the pressure gradient by increasing the choke length, e.g. Linear Pressure Reducer choke.
- Choke polymer concentrate and brine separately and perform dilution of polymer after chokes.
- Use of multiple chokes with each choke set at sufficiently lower differential pressure that is below critical level.

In addition, the knowledge acquired from this test may contribute to improvements of commercial choke valves. Polymer samples prepared at large scale and laboratory scale revealed same rheological properties. Some of the large scale mixing tests suffered, however, from poor water quality, which revealed poor filterability in the filtration tests. With acceptable water quality, the filterability of the two polymers were excellent and similar to the laboratory scale filterability tests. For determination of polymer viscosity and polymer degradation, the poor water quality was not critical, but will be critical in porous media flood experiments (which is planned in a later phase of this project).

Filtration rate or screen factor was found to depend strongly on the viscosity and thereby on the degradation. Upscaled to field conditions this means that some degradation will improve the injectivity. For all polymer samples pH was measured and was found to be relatively constant.

ECONOMIC POTENTIAL

Professor Petter Osmundsen has been leading the project "Economic potential" in The National IOR Centre of Norway. Here presenting at IOR NORWAY 2015.

"THE PROJECT HAS DESCRIBED CHANGES IN COMPANY DECISION CRITERIA AND THE EFFECT ON INVESTMENT INCENTIVES IN GENERAL, AND FOR IOR-PROJECTS IN PARTICULAR."

PROJECT BACKGROUND

A realistic evaluation of the economic viability is essential to any IOR/EOR projects. Input parameters like oil and gas prices, discount rates, capital and operational costs will be reviewed by industry experts. We will use the same type of valuation model as in the petroleum industry, and tax issues will be addressed. When capital and personnel are scarce a particular relevant metric is net present value (NPV) index, in which the value generated is seen in relation to the use of scarce input factors. We will also analyse the effect on production over time (relevant for production targets of the companies), and effects on accounting metrics like Return on average capital employed (RoACE). Finally, we will discuss how the IOR/EOR projects affect bonus schemes prevalent in the oil companies and we will challenge them also to consider EOR from day one.

IOR/EOR projects in mature fields often have a marginal profitability to companies. To society the net present value will be higher, partly due to a lower discount rate, and partly due to the fact that society benefits from gains achieved in all licenses. Part of the project is to analyse the impact of taxation on IOR/EOR projects and whether targeted tax changes can be made for such projects.

DESCRIPTION OF RESULTS ACHIEVED

During execution of the project, decision criteria in the oil companies have changed. When the oil price fell, oil companies implemented stricter capital rationing. First in the form of net present value indexes. When the oil price proved to be more volatile, they shifted to break- even prices. IOR-projects that had problems being funding at the outset, now obviously struggle even more. The project has described changes in company decision criteria and the effect on investment incentives in general, and for IOR-projects in particular. Output has been in the form of publications. Much effort has also been made to present these insights to the public in the form of newspaper interviews and presentation on conferences. In addition, a number of presentations have been held for the research group, so that the economic implications of their research has been clarified.

Capital rationing in the oil companies, implemented by net present value or break-even price, implicitly implies a high discount rate. The government does not have capital constraints and thus has a much lower rate of return requirement. Accordingly, IOR projects that are profitable from the perspective of society may not be sanctioned by the companies. In addition, for projects that are sanctioned, development concepts may have less flexibility and have insufficient preparation for future IOR-efforts. In presentations I have discussed deviations between optimal solutions from the perspective of companies and government, and outlined potential remedies.

An interesting comparison is between Norway and the UK. Norway and the UK have net income systems that are comparable for new projects. Norway starts out by stating that they strive for a neutral tax systems, i.e., a tax system that does not distort private investment decisions. Thus, a project that is profitable (unprofitable) before tax should be profitable (unprofitable) after tax. More precisely, the internal rate of return should be the same before and after tax. This can be achieved by direct expensing of investments. Norway has this for exploration costs, and the UK in addition has it for development costs. In Norway, development costs are depreciated over six years. To compensate for the net present value cost, an uplift was introduced of 30% over four years. The tax system was then neutral for a company with a nominal rate of return requirement about 9.5%. In May 2013 the uplift was reduced to 22%. The tax system is now neutral for an oil company that sanctions petroleum projects at a nominal 7%. For real world oil companies with a higher requirement, the tax system is distorting and leads to underinvestment. The oil companies have higher return requirements and they often demand robustness, so projects below 12-14% are not sanctioned. Thus, underinvestment is the reality, in particular for IOR projects with marginal profitability.

In the UK uplift is not necessary to compensate for the delayed tax deduction, as they have direct expensing. Nevertheless, they have introduced an uplift of 62.5%. The argument is that you only want neutrality when oil companies and government have the same rate of return requirement. Given the fact that oil companies have much higher return requirements – often implemented by net present value indexes or low break-even prices - investment incentives are needed to secure implementation of projects that are profitable to society. The UK tax changes are in accordance with the current business cycle. Meanwhile, Norway is at odds with it. How is the latter possible?

1. Norwegian petroleum taxes are typically more stable than in the UK. The exception was the 2013 reduction in the uplift which should be reversed.

2. The Norwegian shelf is less mature than the UK shelf, and large discoveries are made in recent years. However, the picture is mixed. Targeted tax incentives are needed for segments with marginal to medium profitability, notable mature fields and the Barents Sea.

3. In 2000, a committee headed by a senior official from the Ministry of Finance concluded that the investment incentives of the Norwegian petroleum tax system was too favorable. This is at odds with tax design in other petroleum extraction countries, empirical observations (steep investment decline) and statements from The Norwegian Auditor General, the Norwegian Petroleum Directorate, Petoro and tax researchers that investment incentives for projects on mature fields are too weak.

As for the report from 2000, the committee arrived at its conclusions by making assumptions regarding oil company investment behavior that are counter-factual and at odds with all other reports. It is also at odds with a 2015 committee on onshore taxation, which presumes ordinary investment behavior – the traditional net present value method. The 2000 committee presumed a partial cash flow method in which tax depreciations are separated and discounted with a risk free rate. Thus, current Norwegian tax policy is inconsistent in that it presumes two different investment methods, one for onshore companies and quite another for oil companies.

IORSim

The work with the IORSim has shown a lot of progress.

IOR NORWAY 2015

300 participants, two days. Our first annual conference was great.

LUNCH & LEARN

Food and learning, what could go wrong? These events have been a huge success.

Road map

The construction of the road map was an important event in 2015.

HIGHLIGHTS 2015

SOME OF THE MANY HIGHLIGHTS FROM THE WORK DONE IN THE NATIONAL IOR CENTRE OF NORWAY IN 2015

Open Porous Media

We have contributed to improved function-ality and performance of the OPM black oil simulator.

Yard Test

Large scale test on polymer degradation performed at IRIS.

New tracers

Researchers at IFE have done excellent work in the develop-ment of new tracers in 2015.

Recruitment

A total of 16 PhDs and 10 postdocs are now recruited to The Centre.

Hjelmeland

We gathered the whole IOR Centre team for a two-day strategy seminar.

Joining forces

Joint collaboration between the three research partners and the two service com-panies.

IOR NORWAY 2015

More than 300 people participated in the first annual conference hosted by The National IOR Centre of Norway. 25 speakers shared their views and research on improved oil recovery.

IOR NORWAY 2015

28 APRIL

09:00 Registration

10:00 Welcome to IOR 2015:
Merete Vadla Madland, Centre Director

10:15 Welcome to UiS: John Møst, University Director

10:20 Introduction lecture: Tord Lien, Norwegian Minister of Petroleum and Energy

THEME 1: THE NORTH SEA – THE LEADING PETROLEUM PROVINCE BY 2020?

10:40 "Improved Oil Recovery - Challenges and Opportunities on the Norwegian shelf"
Tomas Mørch, Norwegian Petroleum Directorate

11:00 "Improved Oil Recovery –Do we have the right tools?"
Øivind Fevang, Statoil & OG21

11:20 "Will and skill to find and produce new petroleum"
Hans C. Rønnevik, Lundin

11:40 Lunch

THEME 2: THE OIL INDUSTRY AND EOR

12:40 "Building an Enhanced Oil Recovery Culture to Maximise Asset Value"
Marco Rotondi, Eni

THEME 3: DECISION CRITERIAS

13:00 "IOR decision criteria in times of capital rationing"
Petter Osmundsen, UiS

13:20 "How Much Information is Enough? Value-of-Information for IOR"
Reidar Bratvold, UiS

13:40 Coffee break

THEME 4: PILOTS AND FULL FIELD CRITERIA FOR SUCCESS

14:10 "EOR in the UK – Taking Stock, Looking Forward"
Jonathan Thomas, UK Oil & gas Authority

14:30 "Why is offshore EOR so difficult for mature fields?"
Adolfo Henriquez, Petoro

15:50 "Polymer injection optimization using ensemble methods."
Laura Dovera, ENI

**15:10 "The art of communicating complex topics"
Jo Røislien**

THEME 5: THE DANISH VIEW ON THE NORTH SEA FIELDS

15:20 "Objectives and plans for the Danish Hydrocarbon Research and Technology Centre"
Bo Cerup-Simonsen, The Danish Hydrocarbon Research and Technology Centre

15:50 "Progress in IOR/EOR seen from a Danish perspective, with special emphasis on Chalk"
Flemming Ole Rasmussen, Danish Energy Agency

**16:10 End of day – Practical information
19:00 Dinner: Clarion Hotel, Stavanger**

THEME 6: RESERVOIR CHARACTERIZATION

09:00 "Time lapse seismic – past and future"
Martin Landrø, NTNU

09:20 "Tracer technologies to assess and monitor EOR and IOR projects"
Olaf Huseby, Restrack

09:40 "Inert nanoparticles for the lab and field"
Lawrence Cathles III, Cornell University

10:00 "Reservoir characterization using ensemble based methods"
Geir Nævdal, IRIS

10:20 Coffee break

THEME 7: IMPROVED UNDERSTANDING/MODELING OF THE EOR PROCESSES

10:50 "Modeling and Simplicity: Occam's Razor in the 21st Century"
Larry Lake, University of Texas at Austin

11:10 "Quantifying microbial enhanced oil recovery processes at the pore-scale with microimaging"
Dorthe Wildenschild, Oregon State University

11:30 "Use of Silica and Iron-Oxide Nanoparticles with Specific Surface Coatings for Enhanced Oil Recovery Processes."
Chun Huh, University of Texas at Austin

11:50 "The Effectiveness of Tertiary EOR in Heterogeneous Reservoirs"
Ann Muggeridge, Imperial College London

**12:10 Lunch
13:10 Musical performance**

29 APRIL

THEME 8: CHALLENGES FOR RESERVOIR SIMULATIONS, TODAY AND IN THE FUTURE

13:20 "Challenges in reservoir simulation"
Alf Birger Rustad, Statoil

13:40 "IORSim – an add on tool to ECLIPSE for fast and accurate simulation of multi phase geochemical interactions at the field scale"
Aksel Hiorth , IRIS

14:00 "Compaction - Fluid Flow Interaction: The Hows and Whys of Coupled Rock Mechanics and Flow Simulation"
Øystein Pettersen, Uni Research CIPR

14:20 Coffee break

THEME 9: PORE SCALE FUNDAMENTALS

14:50 "Diagenesis, mineral replacement and porosity generation."
Andrew Putnis, University of Münster (Authors: Andrew Putnis and Christine V. Putnis)

15:10 "Quantitative analysis of nano-pore carbonate rocks and representative sampling for digital rock physics"
Hongkyu Yoon, Sandia National Laboratories

15:30 "Three-phase fluid displacements on the pore scale: method and mechanisms"
Johan Olav Helland, IRIS

15:50 Summing up and welcome to IOR NORWAY 2016 by Chairman Kåre Vagle

"It is a great pleasure to be at the IOR Conference for the first time. The central theme is Joining forces – to recover more - I support that," said The Minister of Petroleum and Energy, Tord Lien in his opening speech.

The need for increased oil recovery has been highlighted in the last few years, and it is The National IOR Centre of Norway's job to find the best possible solutions to improve the recovery rate from the Norwegian continental shelf. 25 speakers, representing both academia and industry shared their visions and experiences during IOR NORWAY 2015.

With more than 300 participants, the conference turned out to be a great success. The Minister of Petroleum and Energy, Tord Lien, had the honor of opening the conference, on the same stage of which he a year earlier had opened The Centre. Several important speakers from the industry and academia participated at IOR NORWAY 2015, such as: Øivind Fevang (Statoil), Larry Lake (The University of Texas at Austin), Larry Cathles (Cornell University), Hans Christen Rønnevik (Lundin) and Ann Muggeridge (Imperial College).

In addition several speakers from The National IOR Centre of Norway presented results and future plans from The Centre: Petter Osmundsen (UiS), Reidar Bratvold (UiS), Geir Nævdal (IRIS), Aksel Hiorth (UiS/IRIS) and Johan Olav Helland (IRIS).

Photo: Hans Christen Rønnevik (Lundin)

Photo: Professor Petter Osmundsen (UiS)

"IT IS A GREAT PLEASURE TO BE AT THE IOR CONFERENCE FOR THE FIRST TIME. THE CENTRAL THEME IS JOINING FORCES TO RECOVER MORE - I SUPPORT THAT"

- TORD LIEN
MINISTER OF PETROLEUM AND ENERGY

Photo: Centre Director Merete V. Madland with the Minister of Petroleum and Energy, Tord Lien.

Photo: Professor Ann Muggeridge (Imperial College)

Photo: Professor Reidar Bratvold (UiS)

Photo: Professor Aksel Hiorth (UiS/IRIS)

Photo: Dr. Øivind Fevang (Statoil)

Photo: More than 300 people participated in the first annual conference hosted by The National IOR Centre of Norway.

HJELMELAND

STRATEGY SEMINAR

Photo: Greeting The Centre researchers arriving for the two-day seminar at Hjelmeland.

Sometimes you just need to get out of the office and meet people face-to-face. We invited all the people working for The National IOR Centre of Norway to a two-day seminar at Hjelmeland.

The National IOR Centre of Norway consist of people working from several places in Norway. Even though the majority of the researchers are located at Ullandhaug, Stavanger, it is still important that we make an arena where all the researchers can meet and discuss their projects face-to-face. 22-23 September we did just that. Close to 60 researchers from The Centre joined us at a strategy seminar at Hjelmeland SPA hotel.

The agenda was full from the time we arrived by boat, until we left the next day. During the stand-up sessions all the PhDs in The Centre had exactly five minutes each to explain their work as easy and entertaining as possible. In the end we ended up with three winners: Mona Minde, Eystein Opsahl and Remya Nair.

"The seminar was very important for all of us," says Centre director Merete Vadla Madland.

"We all need to step away from our offices and labs sometimes, and meet each other face-to-face instead. This is how we harvest new ideas and impulses, and how we will ensure a good collaboration between themes, tasks and projects," she says.

Some of the highlights from the seminar include a brief presentation of the roadmap, a tool that will help us make the right decisions to reach our future goals, PhD stand-up and presentations from the task leaders of The Centre.

Photo: PhD Oddbjørn Nødland during one of the presentations at the seminar. To his left PhD Aojie Hong and Chief Scientist Arne Stavland (IRIS)

Photo: Researcher Anders Nermoen enjoying good food and company at Hjelmeland

Photo: PhD Jaspreet Singh Sachdeva was shed to work, also during the dinner.

RECRUITMENT AND EDUCATION

PhD studies are an important part of the University of Stavanger and The Centre's research. They serve two main purposes, namely to educate research personnel and to generate knowledge to disseminate throughout society.

During 2015, 13 new PhDs were recruited and offered a position as PhD candidates at The National IOR Centre of Norway. The total number of PhD candidates adds up to 16 at the end of the year (one of these started in 2016). The candidates are divided within the different tasks and covers a wide range of IOR research. Research training has a high priority, and all our PhD students will be working closely with other research institutions, both nationally and internationally.

In addition to training PhD candidates, key professors teach several courses at BSc, MSc and PhD level, in addition to provide supervision of MSc students during their MSc thesis work. In 2015 20 MSc students were supervised by professors and associate professors connected to The Centre.

The National IOR Centre of Norway employs a total of 8 postdocs, 4 of these were employed in 2015. The postdocs are located at UiS, and the research partners IRIS and IFE in addition to one at TNO, Netherland. Another postdoc position was filled January 2016.

THE POSTDOCS:

Pål Østebø Andersen, UiS
Thomas Brichart, IFE
Kjersti Solberg Eikrem, IRIS Bergen
Trine Solberg Mykkeltvedt, IRIS Bergen
Tuhin Bhakta, IRIS Bergen
Dmitry Shogin, UiS
Yanhui Zhang, TNO, The Netherlands
Teresa Palmer, IFE
Murside Kelesoglu, IFE

THE PHDS:

Mario Silva, Shaghayegh Javadi, Aojie Hong, Oddbjørn Nødland, Mona W. Minde, Eystein Opsahl, Kun Guo, Remya Nair, Jaspreet Singh Sachdeva, Mohan Sharma, Samuel Erzuah, Irene Ringen, Laura Borromeo, Tijana Livada, Yiteng Zhang and Anna Kvashchuk.

PhDs

Oddbjørn M. Nødland

Title: *Core scale modeling of EOR transport mechanisms*

Current reservoir simulation technology does not take into account sufficient physical and chemical details concerning the aqueous geochemistry. For polymer flow specifically, it is important to include computer code in models to better account for how the aqueous phase viscosity depends on shear effects, and on brine chemistry. There is an abundance of observational data that currently lacks an adequate interpretation.

Many an hour have I been agonizing over stupid errors in my C++ code, but lately I feel the tide has turned in the fight against those pesky and evil little bugs!

- Oddbjørn M. Nødland
PhD blog

Kun Guo

Title: Application of metallic nanoparticles for enhanced heavy oil recovery

In North Sea, there are heavy oil fields such as the Mariner and Bressay fields. In-situ viscosity reduction of the oil is considered as the main objective of any recovery process. This has been achieved by reservoir heating using conventional methods such as steam and air injection or unconventional ones that apply electrical or electromagnetic methods. Recently, several studies have shown that the application of metallic nanoparticles and in-situ upgrading of heavy oils are more efficient than the conventional processes. However, most of the studies follow a phenomenological approach. There is little characterization to correlate the properties of the nanoparticles and the resulting recovery factor. The underlying catalytic reactions giving rise to viscosity reduction are not studied in detail. Limited work has been performed on in-situ heavy oil recovery by nanoparticles.

Chemical methods, specifically, the introduction of nanomaterials as catalysts, will be utilized to develop more sustainable and eco-friendly EOR methods.

- Kun Guo
PhD blog

PhDs

Laura Borromeo

Title: Raman and nano-Raman spectroscopy applied to fine-grained sedimentary rocks (chalk, siltstones and shales) to understand mineralogical changes for IOR application

Raman spectroscopy is a non-destructive and quick method to determine mineral phases. The method can identify very rapidly mineral phases. It is the ideal tool for sample material with grain sizes above 5-6 micron. Smaller grains can be analyzed with a nano-Raman application.

There are many unanswered questions about the mechanical behaviour of calcite crystals as they're exposed with different brines (salt solutions).

- Shaghayegh Javadi
PhD blog

Aojie Hong

Title: Robust production optimization

To develop methods to find optimal injection strategies for EOR processes, taking into account the uncertainty in the reservoir description.

Shaghayegh Javadi

Title: Experimental investigation of the effect of fluid chemistry on the adhesive properties of calcite grains

It is well known that the injection of fluids into chalk reservoirs can lead to compaction. Recent experiments and models have shown that these effects may be explained by the interfacial forces that operate in nano-confined fluid films in the near vicinity of grain boundaries. In particular, it has been proposed that the so-called water weakening, where the strength of chalk is inversely proportional to the activity of water in the pore fluid, may be explained by a hydration repulsion due to water adsorption on the calcite surfaces. Weakening in the presence of sulphate ions, on the other hand, is proposed to result from the increased double layer repulsion that arises when sulphate adsorption generates a negative charge on the calcite surfaces. However, the existing theoretical framework for studying these interactions is insufficient to fully understand these effects. Further development in this field needs to progress through experimental investigations.

Because of The IOR Centre, I have the chances to meet researches from other institutes and from other countries.

- Aojie Hong
PhD blog

Eystein Opsahl

Title: Investigating the environmental fate and effects EOR chemicals

The aim is to provide new knowledge about the fate and effect of polyelectrolytes for better understanding environmental consequences of their use; improved methodology for quantifying low concentrations of solved polyelectrolytes in environmental samples and produced water; and to provide a recommendation for choice of polymers for EOR purposes.

I am going to research the effects of some IOR chemicals on the environment, primarily polymers (really very large molecules), that may end up in the ocean and possibly distort the circle of life. Which we don't want to happen since it always comes back to us in the end.

- Eystein Opsahl
PhD blog

Remya Nair

Title: Smart Water for EOR by Membranes

1. Pretreated seawater is used as the source. Concentration of individual ions are changed and passed through different membranes. Identification of the membrane property which is best suited for injection water composition.
2. Using produced water (synthetic) as the raw water source: Identification of simple pretreatment methods for removal of oil and other suspended solids before passing through the membrane.

Mario Silva

Title: Tracer technology for improved reservoir management

The PITT (partitioning interwell tracer test) method was qualified at IFE during the last few years, but the selection of applicable phase-partitioning tracers is limited. There is a need to develop more phase-partitioning tracers with desired properties.

In very simple words, this implies selecting a set of compounds/molecules with target characteristics, and making sure they will behave as we want them to in the harsh conditions of an oil reservoir so that we can retrieve the desired information from them.

- Mario Silva
PhD blog

PhDs

Working with seawater and membranes is very interesting and I have many exciting experiments to look forward to.

- Remya Nair
PhD blog

Yiteng Zhang

Title: Ensemble based production optimization

Gradient-free algorithms for production optimization or optimization of EOR processes under geological uncertainty have gained a lot of interest in the petroleum industry over the last years. Although the number of publications has started to grow, the theoretical understanding of the practical algorithms is still limited. In addition it is not clear what is the best objective function to optimize nor how to parametrize the controls in an efficient way.

Chalk is an extremely interesting material to work with at high magnifications and I am often quite amazed how beautiful structures nature is able to build.

- Mona Minde
PhD blog

A lot of experimental work has been carried out on CO2-Foam coreflood over recent years at UiS/IRIS and UiB to understand the displacement mechanisms.

- Mohan Sharma
PhD blog

Experimental results have revealed that different ions in the water change the macroscopic mechanical behaviour in different ways. For example, sulphate adsorb onto the water-wet chalks leading to a drastic reduction in the elastic and plastic properties.

- Jaspreet Singh Sachdeva
PhD blog

Mona Minde

Title: Micro- and nano-analytical methods to analyze fine-grained sedimentary rocks (chalk, silt and clay) before and after flooding experiments for EOR purposes

To be able to understand EOR mechanisms at pore-scale, a proper toolbox which holds the quality and resolution to study flooded rock samples at nano-scale resolution is required. This toolbox is to be developed during the course of this thesis; hence the EOR mechanisms at pore-scale should be understood.

Jaspreet Singh Sachdeva

Title: How does wetting property dictate the mechanical strength of chalk at in-situ stress, temperature and pressure conditions?

Is sulfate adsorption observed in oil-filled chalks? Can precipitation of magnesium-bearing minerals from when oil is present in the pores? How does sulfate adsorption and magnesium triggered dissolution/precipitation occur in oil-wet cores? Determining and evaluating the effect of wettability alteration on the mechanical properties of chalk will be the main objective of the project.

PhDs

Irene Ringen

Title: Flow of non-Newtonian fluids in porous media

In this project we will develop experimental techniques where the properties of the polymer solution, the properties of the porous media (grain size, mineralogy, wettability), pressure and temperature are changed in a systematic way. The experimental data will be combined with numerical models both on pore scale (Lattice Boltzmann technique), core scale (Darcy scale models) and thermodynamic models for the solution to suggest physical sound models that can be used on Darcy scale in order to predict the behavior from cm to km scale.

Mohan Sharma

Title: *CO2 Foam EOR Field Pilots*

Experimental work has been carried out in laboratories at University of Stavanger/IRIS and University of Bergen over last few years, to demonstrate application of foaming agents for mobility control of CO2 flood in heterogeneous reservoirs, and to understand parameters influencing flow behavior under CO2-foam flood at core scale. However, there is a limited understanding of scaling up lab data to pilot/field scale. This project aims to bridge the gap by conducting a pilot scale study to identify the important mechanisms which are observed at lab scale and are required to describe flow at reservoir scale.

Tijana Livada

Title: Thermal properties of reservoir rocks, role of pore fluids, minerals and digenesis.

The cooling effect when seawater is injected into a warm reservoir leading to changes in the stress state can de-stabilize and possibly deform the reservoir rock.

So in short, I am working with temperature variations, which, if you think about it, is a physical property.

- Tijana Livada
PhD blog

Samuel Erzuah

Title: Wettability estimation by oil adsorption on minerals mainly in contact with the flowing fluid phases

Early evaluation of wettability is crucial for selecting optimum field development options. Information about wettability can be indirectly obtained from logging of other rock properties, but the uncertainty in estimated wettability range is often high. Wettability measurement can be obtained from Special Core Analysis (SCAL), but SCAL data is not early available. The project aims to reduce the uncertainty for early wettability estimates, which will allow more reliable potential estimates for water flooding. This will reinforce the focus on EOR-methods early in the field evaluations and developments. The hypothesis is that it is possible to estimate the wettability of the reservoir rock based on the wettability of the minerals mainly in contact with the flowing fluids phases.

GUEST RESEARCHER: DR. SILVANA BERTOLINO

Dr. Silvana Bertolino was invited to The National IOR Centre of Norway as a guest researcher in 2015. She has a varied background, and proved to be a great asset for The Centre.

WILL YOU TELL US A BIT ABOUT YOURSELF?

"I am a Geologist and got my Doctorate degree in 1989 at the University of Córdoba (Universidad Nacional de Córdoba) in Argentina. My doctorate Thesis was on the appication of clay mineralogy to the study of soils. Then, I was a Post Doctorate in USA at the Clay Laboratory of Indiana University at Bloomington (Indiana) with Dr. Haydn Murray, a world-class clay scientist also devoted to industrial minerals. I worked two and a half years with Dr. Murray and learnt a lot about the origin, identification and applications of clay minerals in different environments. When I went back to Argentina I got a position as a scientist at CONICET, our National Research Council. Since then I have devoted my career to the study of clay minerals and their applications to different fields: Geological, environmental and archaeological. I have given several Courses on clay mineralogy, origin and X-ray identification at different universities in my country as well as in an oil company in Ecuador and a copper mining company in Chile. I am a member of the Editorial Board of Applied Clay Sciences, a Journal of Elsevier, since 2004."

WHY DID YOU CHOOSE TO COME AND WORK FOR THE NATIONAL IOR CENTRE OF NORWAY?

"It was a great opportunity for me, as a scientist to work and be part of this Center of innovation. I have had the chance to learn about the oil recovery and its latest advances. I have also been able to investigate on the applications of clay mineralogy to that field. I have been collaborating with Dr. Zimmermann for over ten years in different projects. In the last years I have been invited to participate on IOR projects assisting on the study of the mineralogical composition of unflooded and flooded chalks."

"PORE SCALE PROCESSES"

JANNE PEDERSEN'S PHD WORK

Janne Pedersen began working on her PhD in 2010 and defended the thesis October 19th 2015. Her PhD was partially funded by The National IOR Centre of Norway.

My PhD work has been to study fluid flow and rock-fluid interactions (chemistry) in the reservoir at the pore scale, which is on the scale at which the oil resides inside the rock, typically micro meters. The understanding of physical and chemical processes in the reservoir on the pore scale is important for interpretation of core flooding experiments, and for future work on upscaling rate laws to the field scale. I have made use of a modern CFD method, the lattice Boltzmann method, to model flow and chemistry in the reservoir. This method was chosen because it is easy to use in complex geometries such as the pore space of a reservoir rock, and because it is applicable to parallel computing, which reduces the computational time significantly.

The objectives of my thesis have been to implement important physical and chemical processes necessary to describe pore space evolution during chemical flooding into a lattice Boltzmann simulator, and to apply tis simulator to interpret lab experiments. Among the achievements is the proposition of a moving boundary routine within the lattice Boltzmann method that is independent of the underlying mathematical grid, and a surface coverage model that gives a dissolution rate that is dependent on surface coverage by precipitating minerals.

I have found the work towards the PhD degree very satisfying, as it has given me new programming and scientific writing skills, and it has given me the opportunity to work with basic processes in physics and chemistry which I find very inspiring. Nevertheless, it has been a long road from I first started the PhD work in 2010 to the defense of my thesis at October 19th this year (2015). With a master's degree in astro-particle physics it has been time consuming to dive into the petroleum business, but it has also been inspiring to work with something that feels somehow more useful for the society. The process of writing scientific papers has been a time consuming one, but as already mentioned, I am thankful for the skills obtained from this process.

It feels kind of strange now that the PhD work is finished. When working with something for so long, at some point it feels like it is never going to finish, and then one day, suddenly it is. At the time of writing it has been two weeks since the defense of my thesis, and I have just had a week of vacation to recalibrate after the intense work before the defense. Now I look forward to continue research work at IRIS without the pressure one puts upon themselves during the PhD work.

DISSEMINATION

Photo: Professors Merete Vadla Madland and Aksel Hiorth as key note speakers at the Norwegian Petroleum Society conference in December.

Photo: Lunch & Learn: Roald Kommedal presenting "Polymers in the environment - Fate and Effects"

Numbers from 2015:

- **50 scientific lectures**
- **14 popular science publications**
- **6 posters**
- **25 academic lectures**
- **4 media contributions**
- **3 software releases**
- **18 academic articles**
- **2 interviews**
- **2 feature articles**

2015 has been a fruitful year when it comes to being visible. The year has been focused not only on the road ahead, and the creation of the road map, but also by being present at conferences, seminars, meetings, workshops and symposiums all over the world.

Professors Merete Vadla Madland and Aksel Hiorth were invited key note speakers at the Norwegian Petroleum Society conference in December. Professor Hiorth was also speaker at the IEA Collaborative Project 36th EOR Workshop & Symposium, along with Anders Nermoen (UiS/IRIS). Ying Guo (IRIS) has a good collaboration with researchers in Brazil, and represented The Centre at the SINOS/IOR Workshop in November. Tuhin Bhakta and Ida Lykke Fabricius represented The Centre at SEG New Orleans 2015. Tor Bjørnstad from IFE was invited speaker at International Atomic Energy Agency (IAEA) General Conference in September. These are only a few of the events where representatives from The National IOR Centre of Norway have been present. For a more complete list, see the CRIstin report in the back or visit our website uis.no/ior.

IOR NORWAY 2015

What better way to disseminate research than to invite the world's leading researchers into your home, or in this case, to the University of Stavanger. The first annual conference by The National IOR Centre of Norway was a success, with more than 300 participants. Our own researchers were present at the conference, some as speakers at the conference or the following workshop, and some as participants - enjoying the networking opportunity the conference provided. New collaborations were made as a direct result of this conference.

LUNCH & LEARN

An easy way to receive feedback and work on your presentation technique, but more importantly - let people know what we are working on in The Centre. These events have been held regularly at UiS, with researchers taking turn presenting their current research. Also PhDs and postdocs have been able to participate here, and benefitted from the feedback and experience they received.

HJELMELAND

At the strategy seminar at Hjelmeland, the researchers at The Centre were coached in how to disseminate their research by the Strategy and Communications department at UiS. Many of the researchers found this very interesting, and made plans on how to make their research more available.

UIS.NO/IOR

The Centre website is updated continuously, with events, current activities, projects and other relevant information.

NEWSLETTER

A Centre newsletter is sent out several times each year. Here you can find the latest updates, interviews with researchers and more. You can sign up for the newsletter from the website.

THE PHD BLOG

All the PhDs in The Centre are asked to write entries to the PhD blog at the website. Here they will explain their projects, their challenges and maybe most importantly - their innovative results.

ECONOMY 2015

OPERATING INCOME AND OPERATING COSTS	2015
(All numbers in 1000)	
Remaining as per 31.12 previous year	6 880
UiS - own contribution	11 475
RCN	9 054
User partners	20 000
User partners - in kind	6 055
International - in kind	254
Other income	316
Total operating income	54 034
Payroll expenses	18 879
Procurement of R&D services	30 543
R&D services - in kind	6 055
International R&D services - in kind	254
Other operating expenses	1 889
Total operating expenses	57 620
Operating profit	–3 586

COMMENTS TO OPERATING INCOME AND EXPENSES IN 2015:

Positive operating profit for NOK 6880 was transferred from 2014 to 2015.

Income from The Research Council of Norway (RCN) includes NOK 251 for 2014 and NOK 8803 for 2015. NOK 4779 will be transferred from RCN in 2016 to cover costs for 2015.

Income includes payments from 10 user partners. They each paid NOK 2000 for 2015.

Halliburton, Schlumberger and DTU each contribute by providing work in kind.

Other income relates to IOR NORWAY 2015.

Payroll expenses include IOR Management, administration, R&D, PhDs, laboratory personnel and student assistants. Real costs versus RCN rate for PhDs.

Procurement of R&D services relates to services from IRIS, IFE, TNO, Bureau Veritas Commodites Canada and The University of Edinburgh.

Other operating expenses relates to travel costs, laboratory costs, profiling, IOR NORWAY 2015, etc.

Negative operating profit for NOK -3586 is transferred to 2016.

WHO ARE WE?

THE MANAGEMENT TEAM:

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UiS

Assistant Centre Director
Kristin Flornes
IRIS

Research Director
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Leader of Task 4
Project manager
Aksel Hiorth
UiS/IRIS

Research Director
Theme 2
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Director of Field
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Sissel Opsahl Viig
IFE

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Svein Skjæveland
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Research scientist
Trond Brenna
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Guest researcher
Silvana Bertolino
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PhD
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PhD
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Mona Minde
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Yanhui Zhang
TNO

Postdoc
Teresa Palmer
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Kjersti Solberg Eikrem
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List of other national and international collaborators, see page 8–11.

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