The National IOR Centre of Norway

ANNUAL REPORT 2016

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OBSERVERS

THE MANAGEMENT

Merete V. Madland
Centre Director

Kristin M. Flornes
Assistant Director

Aksel Hiorth
Director of Research

Randi Valestrand
Director of Research

Svein M. Skjæveland
Director of Academia

Sissel Opsahl Viig
Director of Field Implementation

THE BOARD

Chairman: Kåre Vagle, ConocoPhillips
Thierry Laupretre, Aker BP
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Øystein Lund Bø, University of Stavanger
Ole Ringdal, IRIS
Jon Kvalem, IFE

Observers:

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

TECHNICAL COMMITTEE

Consists of representatives from each user partner

Head of committee: Niels Lindeloff, Maersk Oil Norway AS
Andrea Reinholdtsen, ENGIE AS
Bjørn Gulbrandsen, Lundin Norway AS
Trygve Nilsson, Det Norske Oljeselskap AS
Robert Moe, ConocoPhillips Scandinavia AS
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Lars Sønneland, Schlumberger Norge AS
Siroos Salimi, Eni Norge AS
Knut Uleberg, Statoil Petroleum AS
Eirik Jensen, DONG Energy AS

SCIENTIFIC ADVISORY COMMITTEE

Professor Ann Muggeridge, Imperial College, London
Professor William R. Rossen, TU Delft
Professor Yu-Shu Wu, Colorado School of Mines
Professor Stephan Herminghaus, Max-Planck-Gesellschaft

THE NATIONAL IOR CENTRE OF NORWAY

THE CENTRE BACKGROUND

The world needs energy. Up to present day oil and gas have contributed to the primary energy by more than 80 %, and even in the 2-degree scenario of the United Nations more than 50 % of the total energy needs to come from oil and gas. On the Norwegian Continental Shelf, more than 50 % of the total discovered resources are still left in the ground. There is a great environmental benefit of extracting most of the discovered resources, as existing infrastructure can be used.

The National IOR Centre of Norway provides cost efficient and environmentally friendly solutions for improved oil recovery on the Norwegian Continental Shelf through academic excellence and close cooperation with the industry. The Centre was awarded by the Research Council of Norway after a national competition.

University of Stavanger is the host of The National IOR Centre of Norway, the research institutes IRIS and IFE are research partners. Several other national, international research groups, and 12 oil and service companies, complete the Centre's list of partners and collaborators.

The researchers in the Centre work actively in order to improve the recovery, whilst reducing costs and mitigating environmental impact. To achieve this goal, it is important that all stakeholders work together, and The National IOR Centre of Norway is an important arena for doing exactly this.

PHOTO: ALICE NIELSEN

JOINING FORCES TO RECOVER MORE

OVERALL AIM

The Centre will contribute to the implementation of cost efficient and environmentally friendly technologies for improving oil recovery on the Norwegian Continental Shelf.

SECONDARY OBJECTIVES

- Robust upscaling of recovery mechanism observed on pore and core scale to field scale.
- Optimal injection strategies based on total oil recovered, economic and environmental impact.
- Education of 20 PhD students and 8 postdocs during the lifetime of the Centre.

THE DIRECTOR'S VIEW

2016 has been a truly eventful year for The National IOR Centre of Norway. I can proudly say that we are several steps closer to reaching our goals. The research in the Centre is more focused, active and to the point than ever before. We are actively using the roadmap to ensure that what we do is anchored in our strategies and vision.

We have an amazing group of PhD students and postdocs working in the Centre. In 2016 we had the pleasure of receiving the news that two more PhD students will be joining our team in 2017. This will further strengthen our research.

In 2016 we hosted our second conference: IOR NORWAY 2016. Despite the troubled times in the oil and gas industry, close to 300 participants joined us in Tjodhallen last April. I am so pleased to see that the conference attracts an international audience, and experts from all over the world came together to share knowledge and expertise. New in 2016 were the PhD poster sessions, where PhD students from relevant fields had the opportunity to present their posters, as well as to do a brief stand-up session. An independent jury was appointed to select the most promising PhD candidate. In the end it was the Centre's very own Irene Ringen who won the first ever Skjæveland Award.

None of the achievements made in the Centre would be possible without the support and collaboration from our partners in the industry. The bond between academia and the industry is strengthened through the co-operation in the Centre, and together we will continue following our vision: Joining forces to recover more.

There are several other highlights worth mentioning from 2016: the establishment of our very own Scientific Advisory Committee, our great stand at ONS, where we were also nominated in one of the best stand categories. I would also like to thank all our national and international collaborators. Several of our researchers have benefitted from stays abroad in 2016, and this is truly of high value to The National IOR Centre of Norway.

Merete Vadla Madland
Centre Director

Photo: Elisabeth Tønnessen

MESSAGE FROM THE CHAIRMAN

In 2016 The National IOR Centre of Norway has focused on making the foundation towards the overall goal of providing solutions for improved oil recovery. Understanding the physiochemical mechanisms at pore and core scale through laboratory experiments at reservoir conditions and modelling of these processes are key steps towards achieving realistic upscaling to facilitate the ultimate testing at field scale.

Environmental impact and cost are other fundamental aspects with high attention. Larger scale testing onshore may become a vital intermediate step towards a full field pilot to reduce risk and cost. However, access to sufficient field data will continue to be critical for obtaining the key deliverables needed to materialize field pilots.

The merger of BP and Det Norske into AkerBP caused reduction of industry funding and forced the Centre to make some necessary prioritizations in planning for 2017 activities. Guidelines to facilitate for late participant entries into the consortium were subsequently established and attracting new industry partners will be on the agenda going forward.

Kåre R. Vagle
Chairman of the Board

Photo: Elisabeth Tønnessen

MANAGEMENT

MERETE VADLA MADLAND is professor in reservoir technology at the University of Stavanger. In autumn 2013 she was appointed Director of The National IOR Centre of Norway. She holds a Dr. ing.-degree in geomechanics from the University of Stavanger and has been supervising more than 150 undergraduate and graduate students. The last 17 years she has worked on developing new methods for effective extraction of oil from reservoir rocks. She has been heading several research projects funded by the Research Council of Norway as well as a number of industry funded projects. Her research focuses 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. Her 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, Lyse's Research Award in 2013, and her research is presented in more than 100 scientific publications. She has given several keynote presentations at national and international conferences/symposiums. Madland has served on numerous boards and has been member of the Programme Board/Expert Committee for FRINATEK since 2014.

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 CO_2 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 CO_2 capture and storage technology.

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 for Theme 1 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 published more than 75 scientific papers. 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.

RANDI VALESTRAND is the Research Director at IRIS heading the Reservoir group located in Bergen. Valestrand is research director for Theme 2 in The National IOR Centre of Norway. She 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 worked as project leader for large projects sponsored by the industry and the Research Council of Norway.

SISSEL OPSAHL VIIG is holding a position as a senior scientist with the Petroleum Technology Division at Institute for Energy Technology (IFE). Viig is director of Field Implementation in The National IOR Centre of Norway. She has a master degree in nuclear chemistry from the University of Oslo. Since 2003 she has worked with research within tracer technology with main focus on development of tracer methods for reservoir evaluation, tracer methods for determination of residual oil saturation and analytical chemistry. She is frequently working as project leader for several research projects with national and international industry partners.

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. He is director of Academia at The National IOR Centre of Norway. 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.

Photo: The Management Team of The National IOR Centre of Norway, from the left: Aksel Hiorth (UiS/IRIS) research director of Theme 1, Randi Valestrand (IRIS) research director of Theme 2, Svein Magne Skjæveland (UiS) director of academia, Merete Vadla Madland (UiS) centre director. In front: Kristin Flornes (IRIS) assistant centre director, Sissel Opsahl Viig (IFE) director of field implementation, (Photo: Elisabeth Tønnessen)

INTRODUCING: SCIENTIFIC ADVISORY COMMITTEE

In 2016 the final steps were made towards establishing a Scientific Advisory Committee (SAC) for The National IOR Centre of Norway. The four experts in the committee met with the Centre's management team in December 2016.

SAC MANDATE:

- The main task of SAC is to advise and evaluate the scientific performance of The National IOR Centre of Norway in relation to the Centre's vision, objective and research plans including PhD projects.
- SAC will meet with the Centre's Management Team, Task Leaders and Project Leaders once a year. Between meetings the Centre Director and Theme Leaders are encouraged to seek advice from SAC on important decisions relating to the scientific performance of The National IOR Centre of Norway.
- SAC must be composed of international experts collectively covering the scope of work carried out in The National IOR Centre of Norway.
- The committee will report to the Centre Director and the Management Team.

«As the activity in the Centre has progressed, we felt the need for an external look at the work we do,» says Centre Director Merete Vadla Madland.

As she welcomed the committee to the first official meeting, she highlighted the importance of keeping an open dialogue during the meetings:

«You should not feel like you are being bombarded with PowerPoint slides, feel free to interrupt and ask questions and make this meeting your own,» she said to the members of the committee.

From early on the committee did just this, and the members were highly involved in the meeting, asking questions and getting to know the Centre and the people working there.

The first part of the two-day meeting consisted of briefing the committee on the Centre structure, past, present and planned activities, as well as the background of why the Centre was created. All the research tasks were represented by a task leader or other relevant personnel, and were ready to answer questions from the committee.

The second day of the meeting is dedicated to discussions and feedback, as well as clarifying expectations from both the Centre and from the SAC.

«It is important for the Centre to be met with a critical view. We need these experts to challenge us and drive us forward,» says Madland.

She is optimistic about the future collaboration with the committee:

«I feel like we have a good connection already, and I am looking forward to see what will come of this collaboration,» she says.

Photo: The Scientific Advisory Committee. From the left: professor Yu-Shu Wu, professor Stephan Herminghaus, professor William R. Rossen and professor Ann Muggeridge. (Photo: Elisabeth Tønnessen)

PROFESSOR YU-SHU WU

PROFESSOR, FOUNDATION CMG RESERVOIR MODELING CHAIR, AND THE DIRECTOR OF ENERGY MODELING GROUP (EMG) RESEARCH CENTER IN THE PETROLEUM ENGINEERING DEPARTMENT AT THE COLORADO SCHOOL OF MINES (CSM).

He is a fellow of the Geological Society of America. At CSM, he teaches and carries out research in reservoir engineering, multiphase fluid and heat flow, geomechanics, unconventional oil and gas reservoir dynamics, CO_2 geosequestration and EOR, geothermal engineering, and numerical reservoir simulation. He leads the EMG in its research effort in (1) flow dynamics in unconventional oil and gas reservoirs; (2) coupled processes of multiphase fluid and heat flow, geomechanics, and chemical transport in porous and fractured media; (3) CO_2 sequestration and EOR application; (4) improved formation stimulation/cryogenic fracturing technologies; and (5) advanced reservoir-simulation technologies. Previously, he was a staff scientist with the Earth Sciences Division of Lawrence Berkeley National Laboratory for 14 years (1995–2008). During his career, he has authored or coauthored 110+ peer-reviewed journal papers and 17 peer-reviewed books/chapters as well as 62 SPE papers.

PROFESSOR STEPHAN HERMINGHAUS

DIRECTOR AT THE MAX PLANCK INSTITUTE FOR DYNAMICS AND SELF-ORGANIZATION

Studies in physics and fine arts, PhD in Physics University of Mainz (1989), in 1990 postdoctoral stay at the IBM Research Center, San José, California (USA), German Habilitation at the Faculty of Physics, University of Konstanz (1994), head of an independent research group at the Max Planck Institute for Colloids and Interfaces, Berlin (1996-1999), Professor at the University of Ulm (1999-2003), Director and Scientific Member at the Max Planck Institute for Dynamics and Self-Organization (since 2003) (formerly MPI for Flow Research), Honorary Professor of Physics, University of Göttingen (since 2005).

PROFESSOR WILLIAM R. ROSSEN

PROFESSOR IN RESERVOIR ENGINEERING DEPARTMENT OF GEOSCIENCE AND ENGINEERING, DELFT UNIVERSITY OF TECHNOLOGY

He was formerly Professor at The University of Texas at Austin, and before that a research engineer at Chevron Oil Field Research Co. He has more than 90 peer-reviewed journal publications. Professor Rossen's current research concerns use of foams for diverting fluid flow in porous media, modeling complex transport processes in networks, and understanding flow in naturally fractured geological formations. In 2012 he was named an IOR Pioneer at the SPE/DOE Symposium on Improved Oil Recovery, Tulsa, OK, and he is a Distinguished Member of SPE.

PROFESSOR ANN MUGGERIDGE

PROFESSOR OF RESERVOIR PHYSICS AND EOR, DEPT. OF EARTH SCIENCE AND ENGINEERING, IMPERIAL COLLEGE LONDON.

Professor Muggeridge's research focuses on methods for improving oil recovery. Following her DPhil she worked at the then BP Research Centre, followed by a service company (SSI (UK) Ltd) before joining Imperial College in 1995. From 2006-08 she was a Technology Fellow at BP. She is the chair of the organizing committee for the EAGE IOR Symposium 2017 (held in conjunction with IOR NORWAY) and sits on the technical committee for the SPE Reservoir Simulation Symposium. She has published more than 100 papers.

REPORT OF THE SCIENTIFIC ADVISORY COMMITTEE

TO THE NATIONAL IOR CENTRE OF NORWAY

SUMMARY BASED ON MEETING OF 8-9 DECEMBER, 2016

The program of The National IOR Centre of Norway (NIORC) is impressively broad, deep and ambitious. It is especially challenging to embrace both fundamental research and application within a relatively short time frame for R&D. However, we are satisfied with the fundamentals, scientific approaches, and progress of the work.

Furthermore, the talk by Dr. Lindeloff from the Technical Committee shows that industry is satisfied with the applicability and usefulness of the work in the field. The program is visionary, with a large group of professionals, experts, and graduate students, working together on mechanisms of IOR over a wide range of length scales.

The resulting publication record is very good and several of the groups are world-leading in their backgrounds and topics. In addition, the program has achieved an admirable gender balance, which is very unusual in research in the petroleum industry.

It is good that the program is already planning for continuation and evolution after the current phase of funding is over (subject, of course, to approval of an application for extension). The need for improvement of oil recovery will continue past the current end date, and the current research will identify further improvements to be made in the same processes and other avenues for innovation in the following phase.

The program has focused primarily on two methods of IOR: polymer flooding and low-salinity or smart-water IOR. We believe that this focus is appropriate, given the range of length scales considered. It was not clear to us how the inclusion of foam IOR, as presented in one project, ties in with this focus; we do not mean that the inclusion is inappropriate, but the motivation for that inclusion and how it complements the rest of the programme could be made clearer.

We suggest that the NIORC might pursue closer ties with petroleum research institutes and universities in China, where the largest field applications of polymer and chemical IOR/EOR have taken place for decades.

In summary, the committee finds the breadth, depth and ambition of the program, and the integration of a large, diverse group into a common program impressive. The technical quality and publication record appears very good, but we would like the opportunity to examine the technical details in more detail at the next meeting.

PHOTO: ELISABETH TØNNESSEN

IMPROVING THE OIL RECOVERY FROM THE NORWEGIAN CONTINENTAL SHELF

PHOTO: ALICE NIELSEN

MESSAGE FROM THE TECHNICAL COMMITTEE

2016 was a year with active discussion and good engagement between the industry partner representatives of the technical committee and the students and researchers of the Centre. Apart from the regular meetings in the technical committee which provide a structured frame to discuss progress of the various projects, the Centre activities have provided frequent opportunities for industry partners to engage and interact with the Centres activities in workshops, the annual IOR conference and in dedicated meetings with partners on specific topics.

A significant effort has gone into shaping the biannual project reports, an effort which is highly appreciated by the industry representatives as it helps us keeping our colleagues in the respective companies informed and engaged in the progress of the research activities of the Centre. In a period of low oil prices and uncertainty, being able to document the benefit of our activities is very important. The Centre has done this very well in 2016.

Likewise, being able to articulate line of sight to application of the Centre activities is important for the stakeholders around the Centre as well as to the general public.

The development of the roadmap is a very valuable tool to illustrate how we do this. Specific examples where results and insights from the Centre are made practical and put into application are the polymer yard tests completed during the period, demonstration of cutting edge methods for characterizing rock-fluid systems in the laboratory and the further development of software tools such as the IORCoreSim and IORSim. Significant progress was made on these in 2016 and we in the technical committee look forward to being engaged in their further development.

Niels Lindeloff
Maersk
Head of the Technical Committee

PHOTO: ELISABETH TØNNESSEN

RESEARCH THEMES:

THEME 1:
MOBILE AND IMMOBILE OIL AND EOR METHODS

THEME 2:
MOBILE OIL - RESERVOIR CHARACTERISATION TO IMPROVE VOLUMETRIC SWEEP

THE RERSEARCH THEMES:

The research in the Centre is organised in two R&D themes with seven main Tasks, which are specified by a research plan covering deliverables, milestones and methodologies. Researchers from UiS, IRIS, and IFE serve as task leaders. As an overall strategy in these tasks, we involve researchers from different research environments (Improved Oil Recovery/ Enhanced Oil Recovery, reservoir, chemistry, geology, geochemistry, geophysics, mathematics, nano- science/ technology, biochemistry, environmental, industrial economy) from the partners as well as national and international collaborators.

THEME 1: MOBILE AND IMMOBILE OIL AND EOR METHODS

In Theme 1 the main goal is to understand, model, and upscale the microscopic and macroscopic displacement efficiency when various EOR fluids are injected into a porous rock. The environmental impact is addressed through a fundamental understanding of the amount of chemicals needed to efficiently displace the oil and the fate of the chemicals from the injector to the producer.

EOR fluids interacts with the rock, alters primary mineral phases, and their surface properties. Many EOR fluids are non-Newtonian (e.g. polymeric fluids), which behaves highly non-linear in complex and time dependent flow which is relevant for porous media. To solve these challenges we work at the submicron to characterize the rock before and after flooding, and quantify the changes induced by the pore water. The dynamic of polymeric liquids are investigated experimentally by performing experiments in porous rocks, capillary tubes, and Anton Paar Rheometer. The experiments are interpreted using molecular dynamic simulations, methods based on statistical physics, and by extending Darcy law.

A multi scale understanding of the EOR processes secures that the reservoir scale models we develop are consistent with the underlying physical and chemical processes taking place in the pore space. This in turns allow us in a robust way to evaluate the potential of EOR operations for realistic cases, and the environmental impact.

THEME 2: MOBILE OIL - RESERVOIR CHARACTERISATION TO IMPROVE VOLUMETRIC SWEEP

Theme 2 focuses on integrating all types of data such as pressure data, production data, seismic data, tracer data, geophysical data, and geological data into the field scale simulation models. We put emphasis on real fields and aim to develop methodologies that ease the decision making of a petroleum producing reservoir.

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

RESEARCH TASKS

TASK LEADER: ARNE STAVLAND, IRIS
Arne Stavland is a chief scientist at IRIS where he has worked for 30 years. His main interests are in enhanced oil recovery and chemical water control. He holds an MS degree in physics from the University of Trondheim.

TASK 1: CORE SCALE

The aim of this task is to design novel experiments on core scale and develop models that capture the transport mechanisms observed. The deliverables of this task will be chemical systems that can improve the microscopic and microscopic sweep on clastic and chalk fields.

TASK 2: MINERAL FLUID REACTIONS AT NANO/SUBMICRON SCALE

The research is focused on rock-fluid interactions when injecting fluids into rock formations either clastic or chemical sedimentary rocks. We deliver methods in the field of electron microscopy, Raman spectroscopy, specific surface area measurements and X-Ray Diffraction for further investigations of EOR related experiments in the future. The geology of the hydrocarbon bearing formations plays a significant role in task 2.

TASK LEADER: UDO ZIMMERMANN, UIS
Udo Zimmermann is Professor at UiS. His research has focused on provenance techniques and reservoir characterization using petrography, heavy minerals, and geochemical and isotope geochemical methods in clastic and chemical sedimentary rocks of Archean to Phanerozoic ages.

TASK LEADER: ESPEN JETTESTUEN, IRIS
Espen Jettestuen is a senior researcher at IRIS. His main interests are in rock fluid interactions and how these influence the properties of reservoir rock on the microscopic scales. He holds a PhD in physics from the University of Oslo.

TASK 3: PORE SCALE

The focus in this task is to 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.

TASK 4: UPSCALING AND ENVIRONMENTAL IMPACT

The main objective is to translate the knowledge we have about EOR processes on core scale to field scale. The deliverables from this task will be simulation models and work flows that can be used to design IOR operations and interpret IOR implementations.

TASK LEADER: AKSEL HIORTH, UIS/IRIS

Aksel Hiorth is Chief research scientist at IRIS and Professor within reservoir technology at the University of Stavanger. His main interest is developing simulation models that describe the physical and chemical processes during multiphase flow in porous rocks.

TASK LEADER: TOR BJØRNSTAD, IFE

Tor Bjørnstad is at present Special Advisor at IFE within reservoir technology, and Prof. em. in Nuclear Chemistry at University of Oslo. Main interests: Tracer technology, IOR and flow assurance. He holds a PhD (Dr. Philos.) in Nuclear Chemistry from UiO.

TASK 5: TRACER TECHNOLOGY

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).

TASK 6: RESERVOIR SIMULATION TOOLS

The primary objective of this task is to advance the state-of-the-art of modeling and simulation in context of reservoirs. Such advance is needed to cope with the challenges arising from scientific questions and targets of The National IOR Centre of Norway.

TASK LEADER: ROBERT KLÖFKORN, IRIS

Robert Klöfkorn is a Senior Researcher at IRIS. He holds a Dr. rer. nat. in Applied Mathematics from the University of Freiburg. His research interests are scientic computing and software development with focus on computational methods for partial dierential equations and it's applications.

TASK LEADER: GEIR NÆVDAL, IRIS

Geir Nævdal is working as chief scientist at IRIS. His research interests include reservoir characterization, data assimilation and production optimization, and his main research focus the last decade has been the use of ensemble based methods for updating reservoir models. He holds a PhD in mathematics from NTNU.

TASK 7: FIELD SCALE EVALUATION AND HISTORY MATCHING

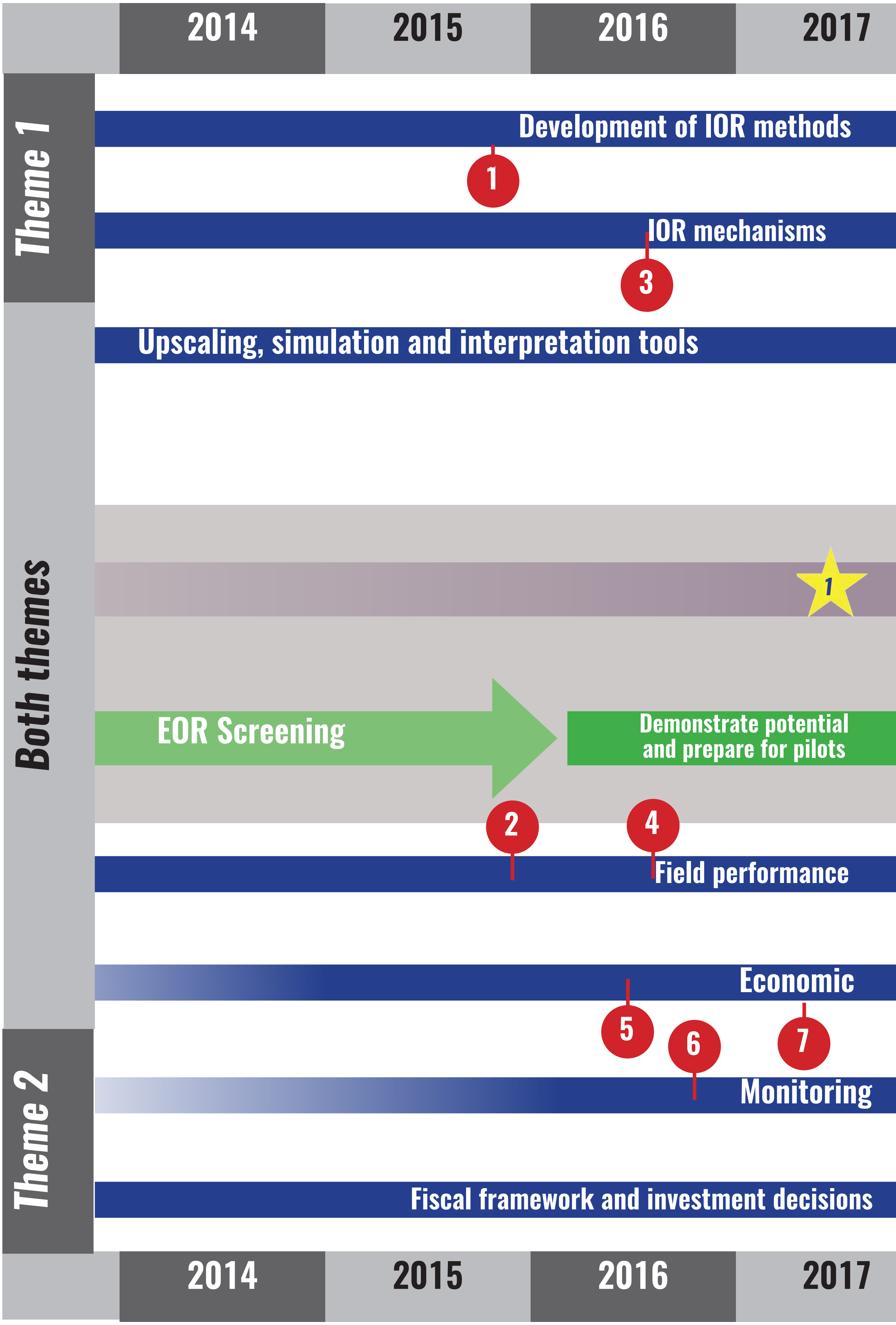
We are focusing on history matching using 4D seismic data, which means that we are tuning reservoir parameters to obtain reservoir models that are matching the actual observations. We are using ensemble based methods to this. That means that we are running with a set (an ensemble) of different realizations 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.

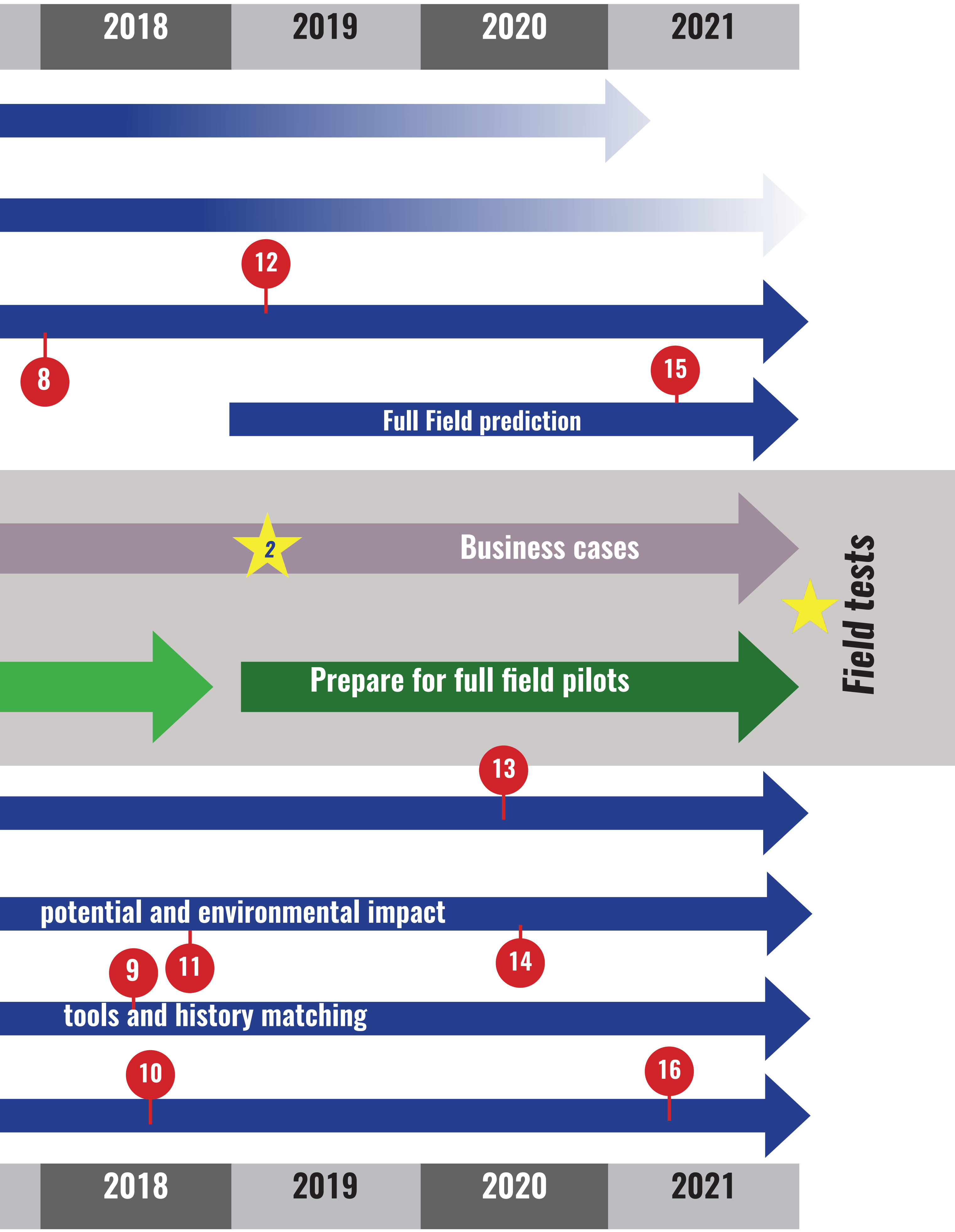
RESEARCH AND DEVELOPMENT ACTIVITIES:

PHOTO: ELISABETH TØNNESSEN

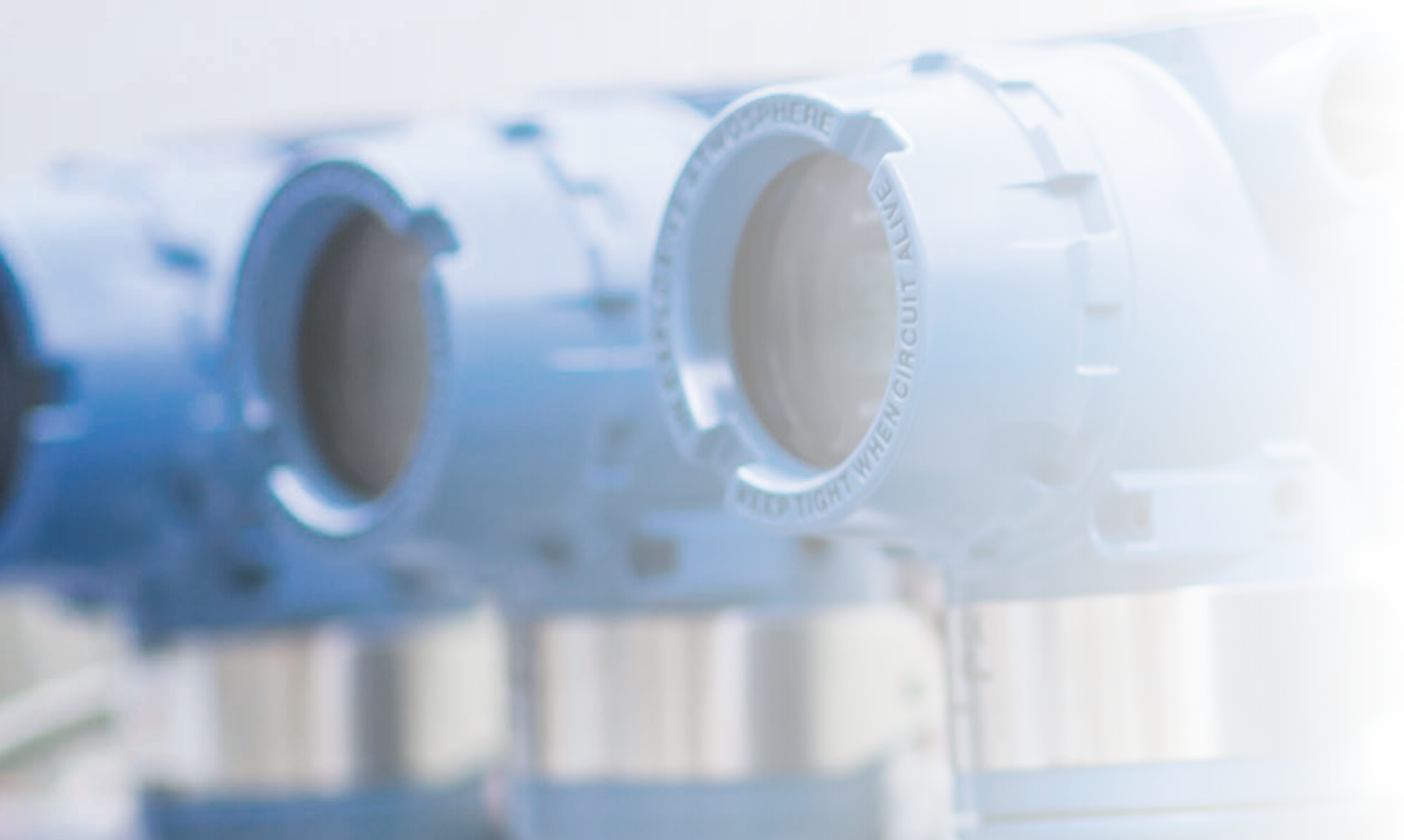

ELVIS

THE ROADMAP


2014
2015
2016
2017
Theme 1
Development of IOR methods
1
IOR mechanisms
3
Upscaling, simulation and interpretation tools
Both themes
1
EOR Screening
Demonstrate potential
and prepare for pilots
2
4
Field performance
Economic
5
6
7
Monitoring
Theme 2
Fiscal framework and investment decisions
2014
2015
2016
2017


2018
2019
2020
2021
12
8
15
Full Field prediction
2
Business cases
Field tests
Prepare for full field pilots
13
potential and environmental impact
9
11
14
tools and history matching
10
16
2018
2019
2020
2021

EXPLAINING THE ROAD MAP



EXPLAINING THE ROAD MAP

The roadmap was established to set the direction of R&D activities in the Centre. This is important so that everyone gets the same understanding of the goals and milestones we have in the Centre. It guides us so that we can more easily focus the research that is being done, and establish good cooperation between the projects. The roadmap is an important tool to evaluate new ideas and project proposals within the timeframes. The map will as such visualize any gaps and be of help prioritizing the R&D projects.

The roadmap is a guiding tool, used to lead the way towards a use case. However, the research in the Centre is not limited to only the roadmap, and in some cases projects will submit valuable input to earlier stages of the map, resulting in better background and understanding for further progress.

THE R&D ARROWS

The blue arrows show the main activities we wish to focus on. All projects should deliver to one or more of these arrows in order to be relevant for The National IOR Centre of Norway. These arrows can include projects from several different tasks, across both research themes; however, some of the arrows are naturally more directed towards projects in one of the two themes.

The green arrows represent overall themes in the research at various times in the lifetime of the Centre: EOR Screening, Demonstrate potential and prepare for pilots and Prepare for full field pilots. It is important to note that The National IOR Centre of Norway will not perform pilots, but contribute with research and results towards this.

PHOTO: ALICE NIELSEN

THE STARS:
1. Selection of suited field for single-well tests (access to field data)
2. Single-well pilot tests:
    - Smart water injection
    - Polymer injection

THE RED MILESTONES
1. Selected IOR methods

2. Field data in place (injection, production and tracer data, 4D seismic and reservoir model/geo-model/geomechanical model)

3. Input model parameters (from pore, core, sub-micron experimental and modeling R&D activities)

4. Large scale polymer shear degradation test

5. Economic potential of IOR methods

6. Monitoring tools: 4D seismic (front detection), tracer data (residual oil S_{or})

7. Conditioning of injection fluids

8. Reservoir simulation, geomechanics (e.g. Eclipse, Visage), tracer and IOR fluid simulation (IORSim)

9. Full field history matching with 4D seismic and tracer data

10. Viability of methods (fiscal framework and taxation)

11. Environmental impact of selected IOR methods

12. Tool-box for interpretation of pilot-tests

13. Pilot-tests conclusions (Volumetric sweep/injection and production strategy, S_{or}, compaction impact, economic potential)

14. Economic potential of pilot-tests

15. Recommendation for comprehensive and full-field tests

16. Economic potential of full-field tests at NCS

Explaining the Milestones
The milestones are important developments in our research that we rely on in order to reach our goal. Each year we will reach several of these milestones, and take one step further towards improved oil recovery. It is important to notice that the milestones do not limit other projects in their progress, even if they do not deliver to a specific milestone at all times. The stars represent use cases that are relying on progress made from reaching the milestones.

We have per 2016 reached a total of six milestones, with another ten to go. These are the milestones we have reached:

- Selected IOR methods
- Field data in place (injection, production and tracer data, 4D seismic and reservoir model/geo-model/geomechanical model)
- Input model parameters (from pore, core, sub-micron experimental and modeling R&D activities)
- Large scale polymer shear degradation test
- Economic potential of IOR methods
- Monitoring tools: 4D seismic (front detection), tracer data (residual oil S_{or})

DEVELOPMENT OF IOR METHODS

An IOR method could be an injection method that is capable of modifying the capillary forces and/or the relative permeabilities of a porous medium, compared to a base case.

In some fields it may be beneficial to change the residual saturation (improve the microscopic sweep) - other fields may benefit from changing the shape of the relative permeabilities (improve the macroscopic sweep).

PHOTO: ELISABETH TØNNESSEN

CONTRIBUTING PROJECTS:

Task 1: Core plug preparation procedures

Task 1: Wettability estimation by oil adsorption

Task 1: Core scale modeling of EOR transport mechanisms

Task 1: Application of metallic nanoparticles for enhanced heavy oil recovery

Task 1: From SCAL to EOR – Phase II

Task 1: How does wetting property dictate the mechanical strength of chalk at in-situ stress, temperature and pore pressure conditions?

Task 1: Flow of non-Newtonian fluids in porous media

Task 2: Raman and nano-Raman spectroscopy applied to fine-grained sedimentary rocks (chalk, siltstones and shales) to understand mineralogical changes for IOR application

Task 2: Micro- and nano-analytical methods for EOR

Task 3: Micro scale simulation of polymer solutions

Task 3: Pore scale simulation of simulation of multiphase flow in an evolving pore space

Task 3: Experimental investigation of fluid chemistry effect on adhesive properties of calcite grains

Task 3: Improved oil recovery molecular processes

Task 4: Smart Water for EOR by Membranes

Task 7: Pilot studies for improved sweep efficiency – coordination and support

It is well known that EOR mechanisms to produce trapped or unswept oil are combinations of miscibility, viscous-to capillary forces and mobility ratio. To utilize the potential of these EOR methods there is a need for better interpretation of core scale experiments.

The project DOUCS – Deliverable Of an Unbeatable Core Scale Simulator aims to develop a tool for improved simulation of EOR processes at the core scale. The developed EOR simulator represents an important tool for interpretation of laboratory work and scaling of the results to field conditions. We will simulate and interpret laboratory core floods and allow extraction of model parameters from experiments (history matching). The model parameters will be used on sector and pilot scale. A prototype MEOR (Microbiological EOR) simulator Bugsim was brought into the Centre as a starting point for the IORCoreSim simulator. The main achievements from the project have been (i) Sequential solver allowing proper handling of capillary pressure at core scale, (ii) Improved transport algorithms, (iii) Ability to simulate various experimental setups, (iv) Geochemical model allowing simulation of brine-mineral interactions, (v) Implicit solution of conductive heat transport and diffusive species transport, (vi) Polymer model handling shear thinning, shear elongation and shear degradation, and (vii) Interpolation model for relative permeability and capillary pressure suitable for surfactant flooding and simple wettability modification.

Results from simulations of the polymer experiments were presented at the ECMOR XV European Conference on the Mathematics of Oil Recovery. The simulator has been used to match spontaneous imbibition type of experiments. The IORCoreSim simulator is gradually being used more in other projects. Examples of that are the use of IORCoreSim for interpretation of special scale inhibitor experiments, for examination of the effect of composite core in SCAL experiment and in education.

The PhD projects on **Core Scale modelling of EOR transport mechanisms (PhD Oddbjørn Nødland)** and **Flow of non-Newtonian fluids in porous media (PhD Irene Ringen)** are strongly linked to the development of IORCoreSim simulator.

The project **SCAL (Special Core Analysis) to EOR** aims to demonstrate methods that can be used to quantify the EOR potential during SCAL experiments. If performing steady-state flood experiments and switching from one set of fluids to another, a shift in fractional flow curves has been found to be a good indicator of the EOR potential. The experimental results on reservoir core material will then be matched with the IORCoreSim simulator.

The project **Core plug preparation procedures** addresses the importance of preparing cores with representative wettability conditions. This is especially important for EOR methods that involve some sort of wettability alterations, such as the used of smart water injection. The following main research tasks have been addressed: (i) developing methods to determine whether the core plugs are contaminated by mud, (ii) Developing a procedure for the selection of Synthetic Formation Water (SFW) composition and (iii) Determining the importance of the oxidation of crude oil during long-term experiments.

In the project **Wettability estimation by oil adsorption** the objective is to develop a method based on the use of Quartz Crystal Microbalance (QCM) to estimate the wettability conditions of reservoir rocks based wettability of minerals mainly in contact with the flowing fluid phase.

In another project on **How does wetting properties dictate mechanical strength of chalk at in-situ stress, temperature and pore pressure conditions (PhD Jaspreet Singh Sachdeva)** the objective is to improve the competence on the interplay between rock-brine and rock oil interactions and how this can be utilized to improve the drainage strategy.

The PhD project on **Application of metallic nanoparticles for enhanced heavy oil recovery (PhD Kun Guo)** aims to develop methods used to catalyst subsurface refinery, which has the potential to lower the mobility ratio and to produce the oil more effectively.

IOR MECHANISMS

IOR mechanisms are broadly divided into two categories:
mechanisms for improving macroscopic sweep efficiency as well as microscopic sweep efficiency.

Mechanisms for improving the macroscopic sweep are mainly linked to control of the phase mobility at different scales and distances from the injection point. It is clearly possible to have excellent control over the mobility on core scale, but on a larger scale different chemicals travel at different speeds. The system that is injected may therefore behave completely differently due to field scale temperature gradients, geochemical interactions, reservoir heterogeneities, adsorption and simply the fact that effective porosity is different for different chemicals (e.g. the polymers are too large to pass through the full pore space).

CONTRIBUTING PROJECTS:

Task 1: Core plug preparation procedures

Task 1: Wettability estimation by oil adsorption

Task 1: Core scale modeling of EOR transport mechanisms

Task 1: Application of metallic nanoparticles for enhanced heavy oil recovery

Task 1: How does wetting property dictate the mechanical strength of chalk at in-situ stress, temperature and pore pressure conditions?

Task 1: Thermal properties of reservoir rocks, role of pore fluids, minerals and digenesis. A comparative study of sandstone, shale and chalk

Task 1: Flow of non-Newtonian fluids in porous media

Task 2: Raman and nano-Raman spectroscopy applied to fine-grained sedimentary rocks (chalk, siltstones and shales) to understand mineralogical changes for IOR application

Task 2: Micro- and nano-analytical methods for EOR

Task 3: Micro scale simulation of polymer solutions

Task 3: Pore scale simulation of multiphase flow in an evolving pore space

Task 3: Experimental investigation of fluid chemistry effect on adhesive properties of calcite grains

Task 4: DOUCS- Deliverable of an unbeatable Core Scale Simulator

Task 6: CO_2 Foam EOR Field Pilots

Task 7: Pilot studies for improved sweep efficiency – coordination and support

THERMAL PROPERTIES OF RESERVOIR ROCKS, ROLE OF PORE FLUIDS, MINERALS AND DIAGENESIS. A COMPARATIVE STUDY OF SANDSTONE, SHALE AND CHALK

The aim of this project is to better understand reservoir stability during oil production, as EOR methods and injected fluid can potentially destabilize reservoirs. A well-known example is the chalk reservoir, Ekofisk, that began compacting during production and water flooding, leading to sea floor subsidence and an increase in water depth.

Chalk is a carbonate rock whose particles originate from skeletons of coccoliths algae, mostly made of calcite grains. The grains are held together by contact cement at short distances and electrostatic forces at intermediate distance, that are dependent on temperature and brine composition. One factor, that could lead to reservoir destabilization and has received little attention so far, is the variation of temperature.

As cold water is injected into a hot reservoir during water flooding, calcite crystals are thermally contracted, and expanded when reservoir temperature is re-established. Because the thermal expansion coefficient of calcite crystals is strongly anisotropic, temperature fluctuations can cause considerable strains and deformation of the reservoir rock.

The effect of temperature cycling has not been adequately addressed in the literature. This mimics the history of a reservoir rock that has undergone oil production and fluid injection, and thus give greater insight to which forces are binding the grains together.

To investigate the universality of these phenomena, the experiments are conducted on three different chalk types: Kansas, Mons, and Humper.

RAMAN AND NANO-RAMAN SPECTROSCOPY APPLIED TO FINE-GRAINED SEDIMENTARY ROCKS (CHALK, SILTSTONES AND SHALES) TO UNDERSTAND MINERALOGICAL CHANGES FOR IOR APPLICATION (PHD LAURA BORROMEO)

Raman spectroscopy is a non-destructive and fast method to determine mineral phases. The method can very quickly, and without long sample preparation, identify mineral phases. It is the ideal tool in sample material with grain sizes above 5-6 micron.

This is a new method to the analyses of reservoir rocks or flooded samples. This method can be widely used in the oil industry and may motivate further applied research, and will assist in the understanding of which processes that control the alterations in texture, chemistry and mineralogy when rocks are flooded by non-equilibrium brines.

We have now an accepted manuscript in a peer-review journal (Journal of Raman spectroscopy), where we have established that the Raman shift can be correlated to the Mg content in chalk and carbonates. This takes minutes and is extraordinary cheap. It also has an enormous potential for application on platforms or on-shore installation where quick information is needed.

MICRO- AND NANO-ANALYTICAL METHODS FOR EOR

To be able to understand and model core-scale and field-scale effects of EOR methods it is important to study these effects at pore-scale. Even though the results may not necessarily be directly up-scaled from pore- to core- and field–scale, understanding the mineralogical changes is paramount to explain changes in geo-mechanical behavior and wettability of the rock.

A huge amount of experiments has been performed studying these chemo-mechanical alterations and many of these mechanisms are well understood. However, several of the alterations produced can be observed only at micron- and sub-micron-scale. The study of these alterations requires methods of investigation that offer imaging and quantification of the chemical composition below pore-scale, often at nano-scale. For instance, a new methodology to prepare samples of the brittle chalk has been established, and analyses on Transmission Electron Microscopy (TEM) provide high-resolution imaging and chemical analyses. In addition, mapping of the mineralogy of several long-term EOR experiments have been performed at core-scale and combined with the TEM analyses.

The overall goal for this project is to through studies at nano-scale be able to understand precisely how EOR mechanisms work at pore-scale, meaning; how, where and when will the mineralogical changes preferentially take place. This is important input parameters for models and simulations of EOR methods

MICRO SCALE SIMULATION OF POLYMER SOLUTIONS

Polymer flooding is a well-known method to increase the viscosity of water and improve the macroscopic sweep in a reservoir. Although the effects are macroscopic the effective rheology is a function of the micro scale pore geometry. Understanding the changes in effective rheology due to the pore geometry will increase the predictive power of the larger scale solvers.

Core experiments have shown that the effective viscosity of aqueous based polymer solution (measured by the pressure drop and flow rate through a core sample) displays three different rheological regimes. At low flow rates, shear thinning dominates. At higher flow rates, the flow resistance increases possibly due to extensional viscoelasticity, and at the highest flow rates, a degradation regime sets in where the polymers break up, and the flow resistance decreases again. From the experiments, it is apparent that the porous media will change the effective behavior of the polymer due to the heterogeneous fluid flow field and the interactions between rock surface and polymer. To account for these interactions in an effective Darcy scale rheology we will include these effects as changing the bulk properties of the polymer fluid and study the effect of geometry with a lattice Boltzmann solver.

PORE SCALE SIMULATION OF MULTIPHASE FLOW IN AN EVOLVING PORE SPACE

The main objective of this project is to obtain high-resolution (~10 nm) three dimensional digital geometries describing the pore space and mineral content of chalk of different origin and at different stages during the chemical flooding.

The pore space geometries are essential in a numerical study of the pore scale oil-mobilizing mechanisms, which is an integral part of the IOR Centre activities. Some of the analyzed rock samples are flooded samples and these may also directly contribute to a better interpretation of core scale experiments. A main objective in this project is also to identify a minimum sample size for Darcy-scale measurements in numerical simulations; a fundamental question in the up-scaling activity of The National IOR Centre of Norway.

Three sets of images from each of the unflooded Liège, Stevns Klint and Mons samples has been generated, together with some 2D projections of mineral content in the samples.

IMPROVED OIL RECOVERY MOLECULAR PROCESSES

Diffuse Particle Dynamics (DPD) simulation results are used to construct generalized rheological models for the effective viscosity of the polymer solution in pore flow. We also develop phenomenological relations for the polymer concentration profile, cross-channel polymer migration, adsorption, that can be incorporated in rheology models.

This project will supply pore scale effects on the effective viscosity of the polymer solution, which will serve as input for core scale modelling. The results can be used in an exploratory manner to suggest desirable polymer properties in polymer flooding.

For example, the DPD simulations will provide an improved understanding of the physical mechanisms behind migration of polymer away from the mineral wall. This understanding can be used to construct phenomenological models for the depletion layer near the wall as a function of polymer length, local shear rate, concentration and salinity. This can again be used to calculate effective viscosities in porous media.

Simulation runs have been carried out to determine the effects of channel width and polymer properties on the depletion layer and therefore on the effective viscosity. We have run simulations for low and high Weissenberg numbers and for a range of channel widths. We have developed a semi empirical model for the effective viscosity as a function of channel width and Weissenberg number which matches the simulation results for confined polymer flows.

EXPERIMENTAL INVESTIGATION OF FLUID CHEMISTRY EFFECT ON ADHESIVE PROPERTIES OF CALCITE GRAINS (PHD SHAGHAYEGH JAVADI)

It is well known that the injection of fluids into chalk reservoirs can lead to compaction. The effect of changing pore fluid chemistry on the mechanical behaviour of chalk has been the subject of extensive study during the past years, but the microscopic origins of the observed effects are still not fully known.

Recent experiments and models have shown that these effects may be explained by the interfacial forces that operate in nanoconfined 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. In this project, we use both atomic force microscopy and surface force apparatus measuring techniques to study the forces acting at the surface and surface topology of calcite samples in reactive fluids.

UPSCALING, SIMULATION AND INTERPRETATION TOOLS

There are several well studied chemical injection technologies applicable to the fields on the Norwegian Continental Shelf.

Thorough laboratory and modeling studies have been performed but there are still research challenges to be addressed. Chemical EOR methods, such as injecting water of a specific composition (e.g. low salinity, smart water), surfactants and polymers, have proven their potential on core scale.

However, additional oil produced at the core scale does not necessarily imply that the field recovery will be similarly increased. Cores are usually 5-7 cm in length and molecular diffusion and end effects are important, contrary to field conditions. The most crucial area of improvement for all methods is proper simulation of the mechanisms on a field scale.

PHOTO: ELISABETH TØNNESSEN

CONTRIBUTING PROJECTS:

Task 1: Core scale modeling of EOR transport mechanisms

Task 2: Raman and nano-Raman spectroscopy applied to fine-grained sedimentary rocks (chalk, siltstones and shales) to understand mineralogical changes for IOR application

Task 2: Micro- and nano-analytical methods for EOR

Task 3: Pore scale simulation of multiphase flow in an evolving pore space

Task 4: IORSim development project

Task 5: Development and testing of nano-particles as tailor-made tracers for improved reservoir description and for measurement of defined reservoir properties.

Task 5: Single-Well Chemical Tracer Technology, SWCTT, for measurement of S_{OR} and efficiency of EOR methods

Task 5: Development of water/oil partitioning tracers for determination of residual oil saturation in the inter-well region

Task 6: Reservoir simulation tools. Adding more physics, chemistry, and geological realism into the reservoir simulator.

Task 6; Advanced Numerical Methods for Compositional Flow Applied to Field Scale Reservoir Models

Task 7: Interpretation of 4D seismic for compacting reservoirs

Task 7: Pilot studies for improved sweep efficiency – coordination and support

Under this research activity, «Upscaling, simulation and interpretation tools», we list some of the projects that have their main contribution towards this activity. For each of the project listed, we give a brief summary of what the research focus has been in 2016.

Different scales have different challenges. Molecular diffusion and end-effects could have a huge impact on the recovery on core scale, but on the field scale cross flow and temperature gradients could have a huge impact on the efficiency of the IOR process. In the lab, it is easy to make the desired brine, whereas off shore this could be very expensive and jeopardize the whole IOR operation.

SMART WATER FOR EOR BY MEMBRANES (PHD REMYA NAIR)

In this project we try to estimate the ability of nano filtration membranes to produce Smart Water from produced water and seawater for enhanced oil recovery. The research consists of membrane process; Nanofiltration (NF) and reverse osmosis membranes, in a unique configuration to arrange water streams of required ionic strength for carbonate and sandstone reservoirs. Both seawater and produced water are used as feed for membranes. Experiments for pre-treatment of produced water are conducted upstream membrane treatment.

Nanofiltration membranes assist in ionic selection of pre-treated produced water and scale prevention for production of Smart Water. Analysis of technical limits of NF membranes showed that nanofiltration is an attractive method for ionic selection with respect to quality performance, cost and power consumption. It was observed that pH has a significant effect on membrane performance with regard to flux and rejection of ions. Highest flux was obtained when the pH was 7.9. Deviations in flux were also observed when feed pH was 6 and 9.7. Nanofiltration experiments were performed for barium removal from Produced Water (PW). NF removed approximately 72 % of barium present in feed water. A process scheme is proposed for producing Smart Water for carbonate and sandstone reservoirs, based on flow rate and ionic selectivity of NF. This scheme proposes the power consumption per cubic meter of PW reused.
The results obtained can be applied in industrial scale-up for predicting water recovery and ion rejection. This information is critical for designing an optimal membrane system. For practical PW applications, appropriate membranes should be selected based on PW quality and required total dissolved solids for Smart Water in different reservoirs.

IORSIM DEVELOPMENT PROJECT

The object is to establish a software that can upscale results from core scale to field scale. This is done by following chemical species and reactions in the flow field of a reservoir simulator, such as Eclipse or Open Porous Media (OPM). Hence, the same geochemical and IOR models can be applied both on the core scale and the reservoir scale. More specifically, the tuning of parameters done in core simulations can be applied in the reservoir simulation.

The main achievements are that we have successfully coupled IORSim to Eclipse both in a forward and backward mode. In the forward mode, we simply use the flow field predicted by Eclipse to advect chemical components and we are able to predict the chemical composition of the produced water due to geochemical reactions in the reservoir. In the backward mode we pass information back to Eclipse and are able to modify the flow path due to the geochemical reactions. The numerical solution is stable and converges to a single solution when the time step between the reservoir simulator and IORSim is not too large. We are currently working on automatic time step control and local grid refinement in IORSim to ensure an exact numerical solution.

LAB SCALE POLYMER TEST IN POROUS MEDIA – SUPPORTING HALLIBURTON'S LARGE SCALE POLYMER SHEAR TEST –PHASE II

We are doing lab experiments to prepare for a large-scale test. There have been concerns in the industry that e.g. polymer degradation could be different in larger samples (meter scale) compared to lab (cm) scale. Together with Halliburton we are designing a novel test with large sand packs that can be used to test IOR methods at scales comparable to pilot scale off-shore. However, before doing a large-scale test which involves large volumes of fluids and many researchers, it is important that the systems are tested in the lab such that we know exactly what kind of data we need from the yard test.

ADDING MORE PHYSICS, CHEMISTRY, AND GEOLOGICAL REALISM INTO THE RESERVOIR SIMULATOR

Improved modeling methodology and simulation capabilities for IOR are important to perform reliable pilot and full field simulations. In this project, we contribute towards the OPM (www.opm-project.com) simulation framework. This is an open source code able of handling industrial relevant models, which provides a platform for testing innovative reservoir simulation developments in general.

In 2016 the postdoc at IRIS continued her work with Sintef Digital on testing and developing fully-implicit higher order methods for improved simulation of polymer flooding. Some work was presented at ECMOR XV (talk and a conference paper) and is submitted as a Journal paper. This work shows that spatial higher-order methods improves the accuracy both for smooth and discontinuous parts of the solution. Also, these methods reduces grid-orientation effects in idealized settings. The next step for this work is to make these numerical methods more amenable for industrial relevant cases and other applications relevant for enhanced oil recovery.

The postdoc at UiS has focused on research related to modelling and interpretation of experimental data within a) brine-mineral interactions in chalk whereby different chalk types were exposed to the same experimental conditions and their response was measured, b) a fracture-matrix model for reactive interactions between brine and chalk, and, c) viscous coupling during multi-phase flow as seen during co- and counter-current flow where relative permeabilities are affected. Effective relative permeabilities were investigated and flow in a matrix block exposed to capillary and gravitational forces. d) Special core analysis (SCAL) tests where capillary pressure and / or relative permeability are measured. Analytical solutions have been derived for particular cases of centrifuge tests, spontaneous imbibition with porous disc and core flooding. In particular, some of the focus has been towards deriving time scales for prediction of properties and equilibrium states in such procedures. The research during 2016 to present has resulted in 1 published journal paper, 3 conference papers (2 to be presented), 4 journal papers in review and several manuscripts in preparation for journals.

The OPM simulator has been further improved and developed in several ways in 2016 and the project has contributed to both the OPM release 2016.10 and DUNE release 2.5. As an example, interaction between IORSim and OPM has been initiated: A first attempt of file-based interaction similar to that between IORSim and Eclipse has been performed. OPM is currently able to run relevant input, but there are still some issues with the resulting restart files that need to be addressed. Output of flow fields is now available in OPM to allow for coupling with IORSim (available in main branch and next release version 2017.04). Another example is the advance made on simulating a single well scenario, e.g. needed to simulate a single well tracer test. In 2016, flow modeling with OPM has been combined with a time-of-flight approach for tracer transport in the near well region.

ADVANCED NUMERICAL METHODS FOR COMPOSITIONAL FLOW APPLIED TO FIELD SCALE RESERVOIR MODELS (PHD ANNA KVASHCHUK)

The project addresses improved simulation tools, which are important for simulation of any IOR processes. In particular, the complex physical and chemical IOR processes are in crucial need of improved simulation tools. We anticipate that the resulting improvements will lead to better decision making and, hence, improve oil recovery on the Norwegian Continental Shelf.

In 2016, a simplified model for testing of higher order methods on corner-point grids has been implemented. Investigations of necessary interfaces changes in OPM have been conducted. A significant effort to improve performance on the one hand and to allow for temperature dependent simulations on the other hand has been carried out. Some of this work was presented at ECMOR XV, and is currently reviewed by a journal.

CO_2-FOAM EOR FIELD PILOTS (PHD MOHAN SHARMA)

CO_2 injection is a proven solution to tap remaining oil, but suffers from phenomena like gravity segregation, viscous fingering and channelling, eventually leading to poor sweep. Foam has been proven as a solution for mobility control in heterogeneous systems at laboratory scale, which can overcome the unstable displacement during CO_2 injection. However, understanding of the displacement process at large scale is limited within oil and gas industry.

In 2016, reservoir oil and core samples were received and a fluid and rock characterization study was completed to prepare relevant inputs for compositional simulation model for pilot area. In the first half of 2016, a preliminary numerical study was carried out to arrive at the well spacing and injection strategy and the project was presented as a poster at IOR NORWAY 2016.

FULL FIELD PREDICTION

How do selected recovery methods behave in full field case?

Core scale experiments can be performed under realistic reservoir conditions (e.g. high temperature, high pressure, live fluids) in the laboratory, thus providing crucial information about recovery mechanisms at a core scale. Cores are usually 5-7 cm in length and molecular diffusion and end effects are important, contrary to field conditions.

At The National IOR Centre of Norway, experimental data from laboratory tests and large scale tests, together with real field data delivered from industry partners, will generate information of generic importance, which will allow us to predict field performance.

This generic data and information will be used together with the modeling tools developed at the Centre to provide recommendations for comprehensive and full-field tests.

PHOTO: HARALD PETTERSEN/STATOIL

CONTRIBUTING PROJECTS:

Task 3: Pore scale simulation of multiphase flow in an evolving pore space

Task 5: Development and testing of nano-particles as tailor-made tracers for improved reservoir description and for measurement of defined reservoir properties.

Task 5: Single-Well Chemical Tracer Technology, SWCTT, for measurement of S_{OR} and efficiency of EOR methods

Task 5: Development of water/oil partitioning tracers for determination of residual oil saturation in the inter-well region

Task 6: Reservoir simulation tools. Adding more physics, chemistry, and geological realism into the reservoir simulator.

Task 6: CO_2 Foam EOR Field Pilots

Task 6: Advanced Numerical Methods for Compositional Flow Applied to Field Scale Reservoir Models

Task 7: Interpretation of 4D seismic for compacting reservoirs

Task 7: Task 7: Data assimilation using 4-D seismic data

Task 7: Pilot studies for improved sweep efficiency – coordination and support

Under this research activity, «Full Field Prediction», we see that close to all projects will deliver in the future, some more than others. Full field predictions of Improved Oil Recovery require integration of a multitude of data, scales and disciplines. The ultimate objective is to optimize both the microscopic and the macroscopic sweep, while considering cost effectiveness and environmental impact.

A project coordinated by Schlumberger Stavanger Research, the management team and the task leaders at the IOR Centre has been put in place to facilitate integration and explore potential synergies between the various research projects. The objective is to investigate how the different projects can contribute to field pilots and field tests on the Norwegian Continental Shelf (NCS).

It has been pinpointed that proper evaluation of research requires at least one common case where all research can be applied and integrated. Focusing on a common case enables and promotes improved collaboration between researchers and highlights how the different projects can benefit from each other. Through a common case study, missing pieces can also be identified.

Ideally, the common case is a real integrated field case provided by an oil company. Some actual field data is available to the researchers at the Centre, but a complete integrated case study is not yet in place. In the meantime, part of the project integration is evaluated in terms of generic case studies.

Figure 1 gives a big picture view of integrated IOR research. For any method proposed to improve oil recovery, a successful reservoir core flood should be in place, showing that the method is successful at core scale. For concrete evidence

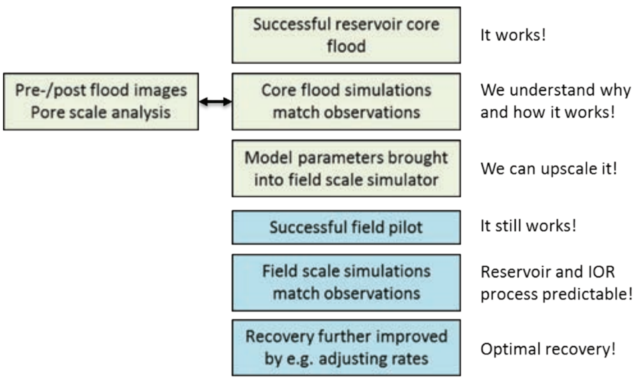


Figure 1 Big picture view of IOR research

of why and how it works, simulations of the core flood that matches the observations are needed. The parameters that govern the process are explored with support from pore-scale and micron-/nano-scale analyses. Once a suitable set of parameters and a reliable match with laboratory data are obtained, the model parameters are transferred into a field-scale simulator. At this point, the method should be pilot tested in the field to confirm that the method also works at field-scale. The pilot test area has to be well chosen and evaluated. After environmental risks are excluded and the operational costs are acceptable, the pilot test can be implemented. The monitoring and evaluation of such a pilot are crucial, ideally involving all available research approaches available at The National IOR Centre of Norway. One of the major strengths of the Centre is the ability to integrate a variety of measurements at different scales, including tracer data and 4D seismic data. Field-scale simulations that match the pilot observations would indicate that the effect of the IOR process can be predicted at reservoir scale, and field-scale implementation can then be considered. However, a decent risk analyses and evaluation of acceptable levels of mismatch has to be executed. To further fine-tune the correlation between the simulations and observations, fast and seamless updates of millions of uncertain reservoir parameters (such as e.g., fault transmissibility multipliers, relative permeability end points, and field properties such as porosity and permeability in each grid block) are enabled by ensemble based history matching using all available observation data, including production data, tracer data and 4D seismic data. Once the reservoir simulation model provides a reasonable prediction of the fluid flow and the recovery of oil, optimization workflows can be invoked to further improve the recovery by for instance adjusting rates.

With Figure 1 in mind, the integration of IOR research implies that researchers have to work together to test, measure, simulate, monitor, predict, and optimize the recovery of oil in a workflow that ranges from laboratory experiments to field implementation. In the end, the contributions to the workflow could be summarized in a set of pictures put together to present the successful development and implementation of an IOR method. A proposed list of pictures is shown in Table 1.

As part of the integration process, researchers at The National IOR Centre of Norway are currently challenged to contribute to such pictures to ensure that an integrated IOR case study is feasible with the current implemented project portfolio.

1. Pictures of reservoir core floods that show improved recovery, supported by images before and after flooding
2. Pictures of core-scale and pore-scale simulations that match lab measurements and images
3. Pictures of equivalent simulation results from a field-scale simulator
4. Pictures of increased production rates, reduced residual oil, improved sweep, and operational/ environmental aspects
5. Pictures of field-scale simulations that match observations
6. Pictures of improved production by adjusting the injection and production strategy

Table 1 Proposed list of pictures presenting the successful development and implementation of an IOR method in an integrated IOR case study.

Most aspects of an integrated IOR case study are actually already in place. Core preparation methods are investigated to make the fluid content and wettability of the core representative of the field. Core floods are analyzed, and adhesion, rock strength, thermal effects, nano-particle effects, spontaneous imbibition, fractional flow curves, relative permeability, and capillary pressures are studied. Core-scale simulation tools are developed, with inputs from micron-/ nano-scale studies of mineralogical changes and pore-scale processes. The core-scale simulations are linked to field-scale simulations. Operational and environmental aspects of pilot implementation are also addressed, including research on membranes to modify the composition of injected water, the investigation of polymer properties as it is brought down to the reservoir and its environmental fate after injection, and pilot testing of CO_2 foam injection. Monitoring tools are represented by tracer data and 4D seismic data and history matching. The basis for the further development and improvement of tracer methods in The National IOR Centre of Norway are recent successful well-to-well and single-well push-and-pull field pilot tests carried out by one of the Centre partners in France and Saudi Arabia. History matching that includes geomechanical impact is also considered. Finally, optimization methods are developed to maximize the recovery by adjusting the injection and production strategy.

During 2016, inputs from all task leaders at the Centre were gathered, and a workshop with the PhD and postdoc students was organized to discuss the status and the way forward. Generic case studies that integrate the results of the IOR Centre are currently under development, and will be used to showcase the impact of the project portfolio in full field predictions of improved oil recovery.

FIELD PERFORMANCE

It is of the utmost importance to be able to describe and generate information of generic significance for particular field conditions in order to be able to predict field performance. Experiments performed in the laboratory and in large-scale tests provide crucial data for evaluating and understanding recovery mechanisms and methods.

Real field data (injection, production and tracer data, 4D seismic and reservoir models, geo models and geo mechanical models) from industry partners at The National IOR Centre of Norway will generate important understanding and, together with data from the laboratory, provide the opportunity to predict field performance in a generic manner.

PHOTO: HARALD PETTERSEN/STATOIL

CONTRIBUTING PROJECTS:

Task 5: Development and testing of nano-particles as tailor-made tracers for improved reservoir description and for measurement of defined reservoir properties

Task 5: Single-Well Chemical Tracer Technology, SWCTT, for measurement of S_{OR} and efficiency of EOR methods

Task 5: Development of water/oil partitioning tracers for determination of residual oil saturation in the inter-well region

Task 7: Interpretation of 4D seismic for compacting reservoirs

Task 7: Data assimilation using 4-D seismic data

Task 7: Pilot studies for improved sweep efficiency – coordination and support

Under this research activity, «Field Performance», we list some of the projects that have their main contribution towards this activity. For each of the project listed, we give a brief summary of what the research focus has been in 2016.

DEVELOPMENT OF WATER/OIL PARTITIONING TRACERS FOR DETERMINATION OF RESIDUAL OIL SATURATION IN THE INTERWELL REGION (PHD-MARIO SILVA)

Tracer technology for well-to well experiments is one of very few applicable technologies for collection of dynamic data of reservoir flows (other technologies being collection and evaluation of "normal" production data, well pressure test analysis and 4D seismic). This allows to back out qualitatively, quantitatively and uniquely interwell flow connections, swept volumes between wells, conducting fractures or barriers to flow, residual (and even remaining) oil saturation in the various swept volumes etc., resulting in a better reservoir description and an improved reservoir model. This technology belongs to the core suite of technologies which are important for improved oil recovery, and the further development of such methods, or certain aspects of these, in order to capitalize on their full potential.

In 2016, full static stability experiments involving the 15 selected PITT (Partitioning Interwell Tracer Tests) tracer candidates were concluded. Results allowed the selection of six of these compounds for continued investigation for use as PITT tracers and excluded the other nine from this application. However, further results from some of the unsuitable compounds suggest the possibility of their use as temperature sensitive tracers and possibly as mineral detection (clay) tracers. A first model for such a purpose was developed and will be further validated. Investigations aiming to identify degradation products are ongoing, as they might confirm or dismiss the possibility of use of at least two compounds as geochemical sensate tracers.

In addition, the development of test methods for analysis of the stable tracer candidates on real field samples was initiated in 2016.

DEVELOPMENT AND TESTING OF NANOPARTICLES AS TAILOR-MADE TRACERS FOR IMPROVED RESERVOIR DESCRIPTION AND FOR MEASUREMENT OF DEFINED RESERVOIR PROPERTIES

Tracer technology for well-to well experiments is one of very few applicable technologies for collection of dynamic data of reservoir flows. This allows qualitative and quantitative interpretation of interwell flow connections, swept volumes between wells, conducting fractures or barriers to flow, residual (and even remaining) oil saturation in the various swept volumes etc., resulting in a better reservoir description and an improved reservoir model.

In this project we aim to demonstrate that nano-sized particles, in this case represented by C-dots, can penetrate a porous medium by following a water flow. This has not previously been demonstrated in interwell experiments. In early 2016, experimental stability experiments on C-Dots provided by Cornell University has started. C-Dots are organic nanoparticles with a size of 2-3 nm. Core-flooding experiments through Berea cores were carried out during the early fall 2016. Before a size stabilization method was proposed, the results showed that the recovery factor never exceeded 70%. This was probably due to the existence of two particle populations, one with small particles acting as passive water tracers, and one with larger aggregates which were partly retained within the porous medium. A succeeding experiment included a filtration procedure to remove the major part of the larger aggregates. In a subsequent flooding experiment, the recovery was measured to 96%.

SINGLE-WELL CHEMICAL TRACER TECHNOLOGY, SWCTT, FOR MEASUREMENT OF S_{OR} AND EFFICIENCY OF EOR METHODS

Tracer technology for single-well (push-and-pull) operation allows a better description of the near-well reservoir area including fracture direction and geometries, depth-differential fluid inflow profiles, potential near-well damage by scaling resulting in permeability reduction etc. In addition, such technologies allow determination of remaining oil saturation in the near-well zone out to some 5-10 meters from the wellbore. This latter may be combined with various EOR-technologies to test the efficiency of various EOR-methods in specific cases. This allows for tailor-making of EOR-strategies in defined reservoirs or reservoir sections.

Traditional SWTT (Single-Well Tracer Test) chemicals suffer from high detection limits. Hundreds of kilograms have to be injected into the formation to allow their detection by gas chromatography on back-production. This project aims at creating new tracers that can be detected at low concentration using fluorescence as the analytical tool. This would considerably reduce the operation time, costs of the test, necessary equipment footprint on the platform, ease the logistics, and improve environmental impact. In addition, an on-site or even online detection of the tracers may be feasible, thus leading to faster results.

Early attempts in 2016 to create multi-ester lanthanide chelates on the basis of the chelate former DTPA proved that this synthetic route was not the best way to proceed: Due to the presence of five carboxylic acid groups in DTPA, a corresponding number of ester groups were formed, to varying degree, in the same molecule. Using this multi-ester molecule in subsequent hydrolysis experiments revealed a considerable complexity in analyzing the results, even in controlled small-scale laboratory experiments. This challenge would multiply in real field experiments. Another approach had to be designed.

Our aim now was to design a synthetic route which would mainly produce a mono-ester. Mono-ester is preferable to multi-ester chelates as only two "similar" compounds would be recovered, one partitioning (the ester) and one passive (the acid produced by the hydrolysis of the ester). Several ester molecules were synthesized based on this chemical "trick". A full fluorescence characterization (including emission and excitation spectrum as well as lifetime measurement) of the fluorescent signal (so-called time resolved fluorescence) showed unique lifetimes for every new tracer candidate (lanthanide chelates) making them both detectable and distinguishable from one another.

ECONOMIC POTENTIAL AND ENVIRONMENTAL IMPACT

All projects at The National IOR Centre of Norway should consider the environmental impact they might cause. All researchers are expected to strive to develop and use the most environmentally friendly technologies possible.

One of the projects is dedicated specifically to providing knowledge about the ultimate long-term fate and ecological effect of EOR polymers.

It is also vital to ensure that the economic potential of the technology developed is relevant for real use. The research carried out at the Centre should be affordable for use in the field, without posing a great economic risk for the industry.

PHOTO: LARS GUNNAR DAHLE/UIS

CONTRIBUTING PROJECTS:

All projects contribute to this topic.

Under this research activity, «Economic potential and environmental impact», we list some of the projects that have their main contribution towards this activity. For each of the project listed, we give a brief summary of what the research focus has been in 2016.

PRODUCTION OPTIMIZATION

Evaluating the economic potential of applying an IOR method is a crucial decision step. In the evaluation, the strategies must be optimized, preferably taking the uncertainty in the reservoir description into account. Here we assume that the uncertainty description is available in the form of a set (an ensemble) of different reservoir models, and the strategy is optimized over those.

In 2016 Andreas S. Stordal, IRIS had a stay at TU Delft and started a cooperative research task with TNO and TU Delft on investigating adaptive multi-scale techniques for the reservoir domain to speed up the computation for the EnOpt algorithm. The grid refinement is based on the flow pattern relevant for the optimization problem at hand. Furthermore, using multilevel grid size (fine to coarse scale) it is possible to improve the gradient estimate by running the simulator many times on a large scale and only a few times on fine scale. The theory of multi-level grid size has already been established for reservoir prediction, but not for optimization.

ROBUST PRODUCTION OPTIMIZATION (PHD-AOIJE HONG)

Since the geological properties of a reservoir can never be known for sure, it is important to make decisions with the consideration of geological uncertainties. This makes the decision robust to the geological uncertainties, i.e. the decision is optimal with respect to the expected value over multiple realizations rather than the value of a single realization.

In 2016 the research on using the Capacitance-Resistive Models (CRMs) for rapid robust production optimization has been further investigated. The performance of the CRMs has been compared with traditional grid-based reservoir simulations, for the problem of production optimization of water flooding. The CMRs approach improved the computational efficiency more than thirty times, a different optimal solution was found and comparable NPV (Net Present Value) was obtained. Initial results were presented at IOR NORWAY 2016, a conference paper was published at ECMOR XV, and a Journal paper is on its way.

ASSEMBLAGE OF DIFFERENT STEP SIZE SELECTION ALGORITHM IN RESERVOIR PRODUCTION OPTIMIZATION (PHD- YITENG ZHANG)

A successful production optimization within the framework of closed loop reservoir management depends on how accurately the numerical optimization scheme has been chosen. This project addresses the theoretical foundation behind the workflow of the production optimization, emphasizing the scientific support for the step size selection, which essentially serves as a tool for evaluating different IOR pilots. To investigate this, several different strategies of step size selection are studied.

In 2016 we have focused on implementing trust-region methods to optimize the objective function, providing a way to increase the robustness and accuracy when selecting the new step in an adequate form. By doing so, the algorithm can adaptively generate a step size parameter to give a substantial increase of net present value, and at the same time, the algorithm does not spend too much time making the choice. For comparison between different frameworks, algorithms are tested using a benchmark five spot problem. Two abstracts regarding this project have been sent to conferences for review.

ENVIRONMENTAL FATE AND EFFECT OF EOR POLYMERS (PHD-EYSTEIN OPSAHL)

Polymer flooding is one of the key technologies being researched at The National IOR Centre of Norway and is a mature technology. However, polymer flooding has, in comparison with the other researched EOR technologies, some extra environmental challenges associated with its use. There is a chance that some polymer can end up in the ocean due to the large volumes used in a polymer flood and the difficulties of treating viscosified produced water at offshore locations. We know very little about the polymers long-term fate and effect in the environment. This project takes aim to broaden our understanding about polymers biogeochemical behavior in the marine environment.

The main achievements through 2016 are related to the analytical chemistry of the polymers. Until very recently, there has been very limited options for determining polymers molecular weight distribution, a key measure needed to quantify degradation. Even less so for polymers in dilute and complex media. Much of the resources available to this project has been dedicated to mastering the heavy theory and application of MALLS together with two key separation techniques. Namely, size exclusion chromatography and flow field fractionating. 5 months during 2016 has been spent at the University of Pau (Fr) to undergo training with such equipment that we now also have at the University of Stavanger. To date we have successfully isolated and measured molecular weight distribution of polymers exposed in marine waters at 10 pm for more than 3 months. With further refinement, we can perform marine degradation studies with an unprecedented level of detail.

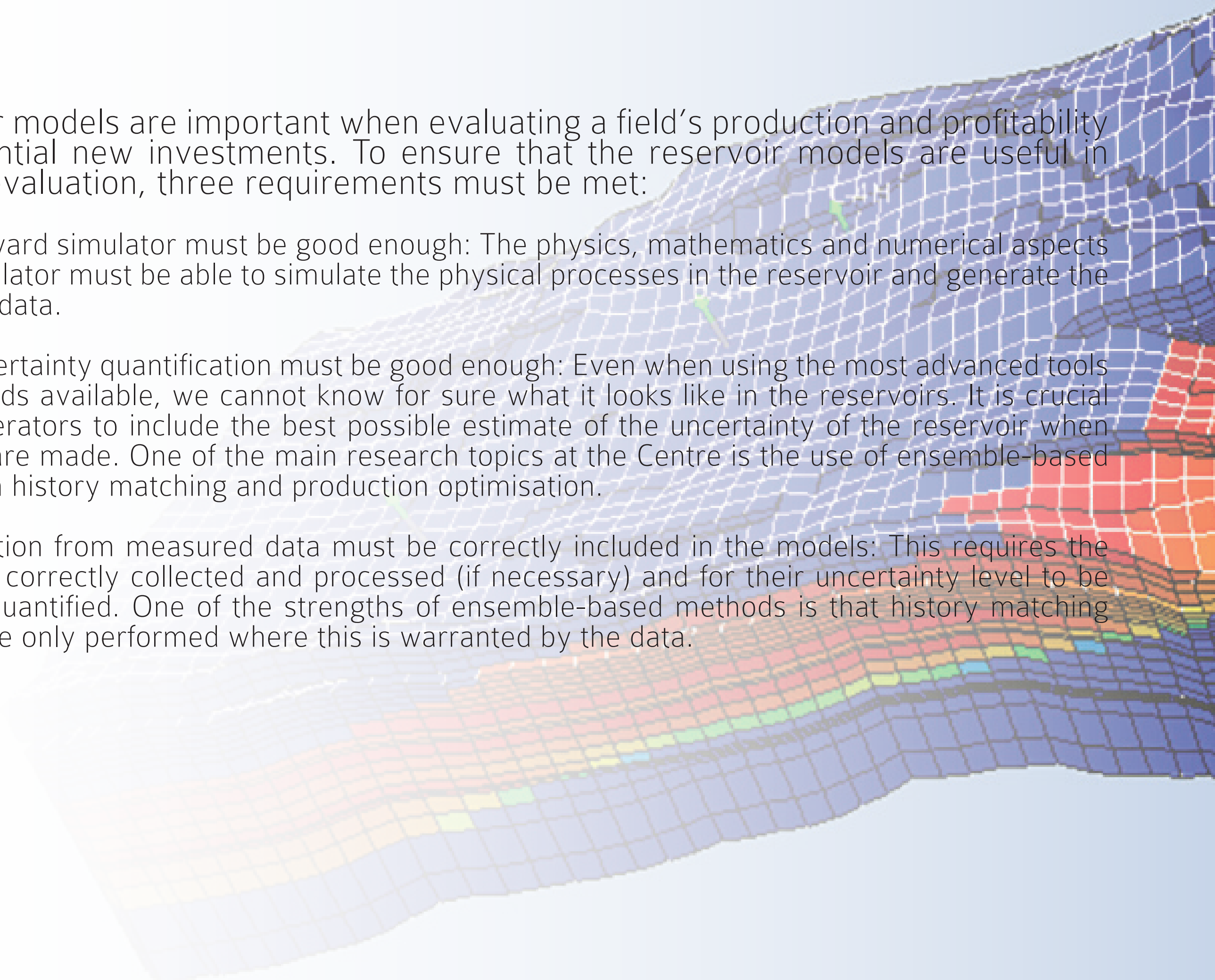
MONITORING TOOLS AND HISTORY MATCHING

Reservoir models are important when evaluating a field's production and profitability and potential new investments. To ensure that the reservoir models are useful in such an evaluation, three requirements must be met:

1. The forward simulator must be good enough: The physics, mathematics and numerical aspects of the simulator must be able to simulate the physical processes in the reservoir and generate the measured data.

2. The uncertainty quantification must be good enough: Even when using the most advanced tools and methods available, we cannot know for sure what 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 are made. One of the main research topics at the Centre is the use of ensemble-based methods in history matching and production optimisation.

3. Information from measured data must be correctly included in the models: This requires the data to be correctly collected and processed (if necessary) and for their uncertainty level to be correctly quantified. One of the strengths of ensemble-based methods is that history matching updates are only performed where this is warranted by the data.



CONTRIBUTING PROJECTS:

Task 5: Development and testing of nano-particles as tailor-made tracers for improved reservoir description and for measurement of defined reservoir properties.

Task 5: Development of water/oil partitioning tracers for determination of residual oil saturation in the inter-well region

Task 5: Single-Well Chemical Tracer Technology, SWCTT, for measurement of S_{OR} and efficiency of EOR methods

Task 6: Reservoir simulation tools. Adding more physics, chemistry, and geological realism into the reservoir simulator.

Task 6: CO_2 Foam EOR Field Pilots

Task 6: Advanced Numerical Methods for Compositional Flow Applied to Field Scale Reservoir Models

Task 7: Interpretation of 4D seismic for compacting reservoirs

Task 7: Data assimilation using 4-D seismic data (Postdoc TNO)

Task 7: Data assimilation using 4-D seismic data

Task 7: 4D seismic and tracer data for coupled geomechanical / reservoir flow models

Task 7: Pilot studies for improved sweep efficiency – coordination and support

Under this research activity, «Monitoring tools and history matching», we list some of the projects that have their main contribution towards this activity. For each of the project listed, we give a brief summary of what the research focus has been in 2016.

DATA ASSIMILATION USING 4D SEISMIC DATA

This project is the main project addressing history matching within the IOR Centre. Decisions on implementing new IOR methods must be taken based on the best available models utilizing all available data. Due to the challenge in building good reservoir models utilizing available 4D seismic data, this is the focus for further development of methodology for ensemble based history matching. Ensemble based methods for history matching are well developed for production data.

Typical seismic data used for history matching, such as acoustic impedance, are inverted quantities, whereas extra uncertainties may arise during the inversion processes. We have proposed a new framework where we avoid such intermediate inversion processes. In addition, we also adopt wavelet-based sparse representation to reduce data size. Concretely, we use intercept and gradient attributes derived from Amplitude Versus Angle (AVA) data, apply multilevel Discrete Wavelet Transforms (DWT) to attribute data, and estimate noise level of resulting wavelet coefficients. We then select the wavelet coefficients above a certain threshold value, and history-match these leading wavelet coefficients using an iterative ensemble smoother. As a proof-of-concept study, we first applied the proposed framework to a 2D synthetic case originated from a 3D Norne field model, before proceeding to a synthetic 3D model. The results, so far tested on synthetic cases, are presented in two conference papers, one journal paper, and a second journal paper is also submitted.

In the joint work between IRIS and UiB in 2016, a Bayesian nonlinear full waveform inversion (FWI) method has been developed to get an estimate of the uncertainty in the seismic inversion. A good estimate of the uncertainty is important for integration of 4D seismic data with production data in history matching. The method is based on an explicit representation of the data sensitivity function in terms of Green functions, rather than the more common indirect optimization approach based on the adjoint state method. The results for a synthetic 2D example will be presented in a conference paper (EAGE/IOR NORWAY 2017), and later a journal paper for the 3D case is planned.

In another research activity, we have focused on estimating observation errors of seismic data using an image processing approach. Three types of image denoising methods were considered, namely, local moving average with different window functions, non-local means denoising and wavelet denoising. The performance of these three algorithms was compared using both synthetic and field seismic data. It was found, from the investigated cases, that the wavelet denoising method leads to the best performance most of the time. The work is presented as a journal paper.

INTERPRETATION OF 4D SEISMIC FOR COMPACTING RESERVOIRS

The main objective of this project is to improve the usage of 4D seismic data to locate gas, water and pressure fronts in compacting reservoir scenarios. This is important to monitor a water front movement as well as creation of gas pockets due to pressure depletion inside the reservoir. Further on, we plan on focusing on history matching using 4D seismic for compacting reservoirs.

The project aims at better utilization of time-lapse seismic data for compacting reservoirs. Discrimination of pressure and saturations from AVO data becomes complicated for compacting reservoirs due to compaction. Here, we focus on resolving the problems connected to these complications and develop improved inversion methodology. The method was proposed and demonstrated on synthetic data for a compacting reservoir scenario, where a very simple rock-physics model was used for the purpose. A journal paper is submitted for publication based on the results on synthetic data analysis. We are also testing the new methodology using real seismic data from the Ekofisk field, and regular meetings with Conoco Phillips experts are carried out in this regard.

DATA ASSIMILATION USING 4D SEISMIC DATA (POSTDOC TNO)

4D seismic data provides abundant information about dynamic changes in the reservoir which are vital for improving reservoir monitoring and management. However, quantitative use of 4D seismic is still challenging. This project aims to find an efficient way to incorporate 4D seismic data into history matching process with a focus on real field data which will contribute to increase the reservoir's oil recovery. For this state-of-the-art data conditioning and statistical methods are required to better define the oil-water-contact thereby improving history matching performance.

In 2016, the applicability of TNO's ensemble-based history matching workflow has been improved by extending it to reservoir models with corner-point grid and making it more robust for models with complex saturation-front patterns. A synthetic case study with the Norne full-field model was implemented and used to verified the effectiveness of the improved TNO's history matching workflow. The results were summarized into a paper that was submitted to the journal of Computational Geosciences, the work was also presented at the ECMOR XV conference.

4D SEISMIC AND TRACER DATA FOR COUPLED GEOMECHANICAL/RESERVOIR FLOW MODEL

Analysing fluid flow and geomechanical effects and building and updating coupled fluid flow /geomechanical models using 4D seismic data is a key step in understanding the effect of injection and production on the reservoir and the surroundings, and such methodology is required to evaluate the field scale effects of a given IOR method.

The work in 2016 has focused on establishing a workflow for simulating overburden geomechanical effects using dynamic boundary conditions from time-lapse data. A workflow for analyzing dynamic fracture behavior is tested on Ekofisk data.

FISCAL FRAMEWORK AND INVESTMENT DECISIONS

When the oil price fell, oil companies implemented stricter capital rationing. Firstly 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 with funding at the outset now obviously struggle even more.

Throughout the Centre's lifetime, researchers will work on evaluating the potential for investment decisions for the companies, and how these will relate to the research performed in the Centre.

This is important in order to ensure that the research continues to be relevant and applicable. To correctly evaluate this, the research develops and uses ensemble-based optimization methods with the capacity to include geologically realistic uncertainty in the evaluation of a reservoir's future behaviour.

PHOTO: SHUTTERSTOCK

CONTRIBUTING PROJECTS:

Task 7: Production optimization

Task 7: Data assimilation using 4-D seismic data

Task 7: Pilot studies for improved sweep efficiency – coordination and support

Task 7: Robust production optimization

Task 7: Assemblage of different step size selection algorithms in reservoir production optimization

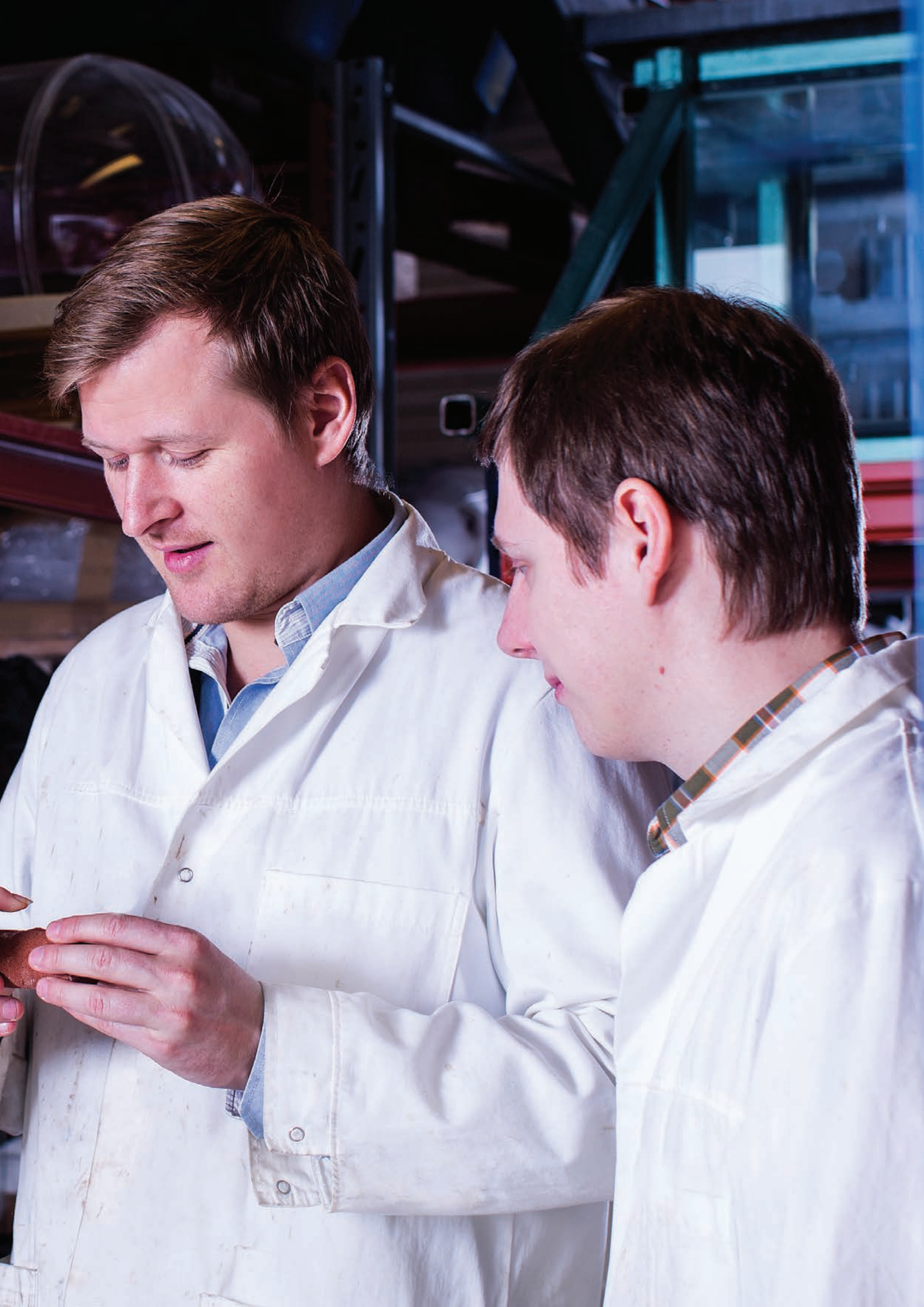
All Centre projects have to evaluate the economic potential of their proposed IOR methods, as commented under the research activity «Economic potential and environmental impact». In this research activity, «Fiscal Framework and Investment decisions», we mainly consider the economic viability of IOR/EOR methods on the Norwegian Continental Shelf from the economists, companies and politicians point of view. The output from this research activity has been in the form of scientific publications, oral talks, and interviews, and, it should be especially mentioned that a significant amount of this dissemination is aimed for the general public, such as interviews and newspaper articles.

As an example of the 2016 dissemination, here is a part taken from the newspaper article written by Petter Osmundsen (UiB) and Atle Blomgren (IRIS) called «Den gamle og den nye oljen». (Published in Dagen Næringsliv December 2016. Translated by Randi Valestrand)

«The Norwegian oil industry has gone through a rough period of cost cuts. An analysis from the Norwegian Petroleum Directorate, considering eight planned developments about to start, indicate that the cost of developing new fields in the North Sea has reduced with 40 % since fall 2014. The reduction is caused by a combination of simpler infrastructure and more efficient drilling. In addition, the price on labor and equipment has been reduced. At the same time the oil price seems to increase again, several prognosis has moved from 40 to 60 dollar per barrel. More than half of the resources remains unproduced. We are close to the bottom of the economic downturn and believe the arrow will start pointing upwards again.»

SELECTED RESEARCH ACTIVITIES

PHOTO: ELISABETH TØNNESSEN



EFFICIENT BIG DATA ASSIMILATION THROUGH SPARSE REPRESENTATION

BY XIAODONG LUO

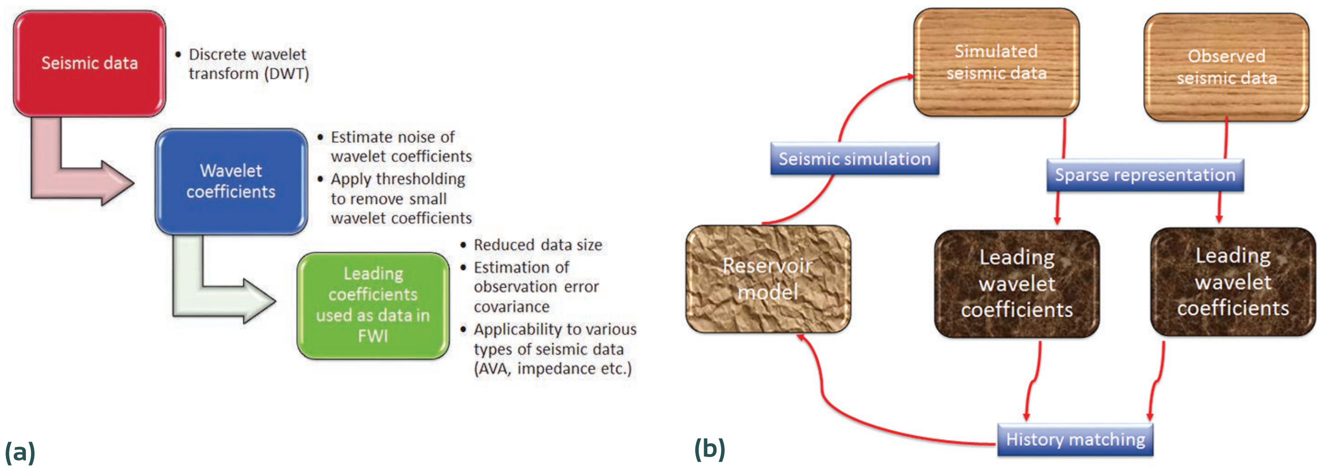


Figure 1: Figure 1: (a) Wavelet-based sparse data representation; (b) History matching with wavelet-based sparse representation.

The advance of modern technologies has led to a massive growth of high-resolution observational data in geosciences. For instance, in the petroleum industry, Permanent Reservoir Monitoring (PRM) system is the cutting-edge technology used to collect 4-dimensional (4D) seismic data for reservoir monitoring, characterization and management. The frequent multiple vintages of 4D seismic results in huge volumes of observed data, thus there is a high demand from the petroleum industry for efficient methods of big data analytics to extract, analyse and utilise the information from big 4D seismic data.

In reservoir engineering, ensemble-based methods (Evensen, 2009) are among the state-of-art history matching (also known as data assimilation) algorithms. When applying ensemble-based methods to history-match seismic data, additional challenges may arise due to the effects of big data sizes. Therefore, to handle big seismic data, it is necessary to adopt a certain data thinning procedure to reduce the data size before history matching. A natural choice in this regard is to select a subset of big seismic data based on a certain criterion. By doing so, however, the information content in the rest of the seismic data will be lost.

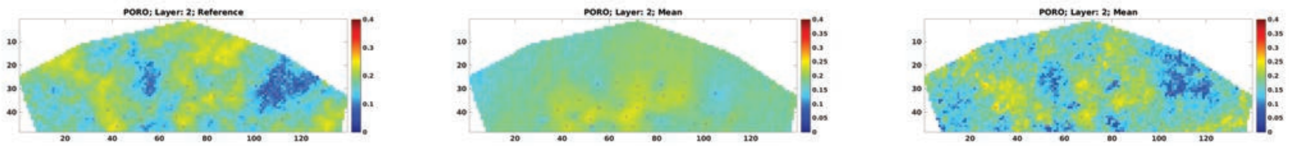
In a recent work (Luo et al., SPE Journal, 2016), Luo and his colleagues at IRIS introduced a wavelet-based sparse data representation procedure (Figure 1(a)) to generalise and extend the rationale behind subset selection, and proposed a new seismic history matching framework (Figure 1(b)) by integrating the sparse representation procedure into the history matching loop.

In the wavelet-based sparse data representation procedure

Comment from the industry:

«Accurate reservoir models are essential for making predictions about future reservoir behavior and subsequent optimization of oil production. Due to the complexity of reservoirs in general and the limited amount of information available, the reservoir property models on which the reservoir simulations are based will always be uncertain. Optimal use of all available data will contribute to reduce this uncertainty. 4D seismic can be an extremely useful tool for detecting injection/production induced time-lapse changes in the reservoir, and can be an important data type for model updates. One big challenge is how to extract the right information from large amount of 4D seismic data and incorporate this information on conditioning with other information, such as production data, log data, etc. The work done in this project propose one way to tackle this challenge by reducing 4D seismic data size substantially using a sparse representation in wavelet domain. In addition, the noise level of the wavelet coefficients is estimated and used in conditioning. This method is novel and has potential to be applied in real field case.»

Tao Feng
Statoil



(a) **(b)** **(c)**

Figure 2: (a) Reference porosity field (layer 2) of the 3D benchmark case; (b) Initial guess of the reference porosity field; (c) Estimated porosity field (layer 2) obtained by using around 1700 leading wavelet coefficients of the original seismic data (around 7 million) as the data in history matching.

(Figure 1(a)), one first applies a discrete wavelet transform (DWT) to the seismic data, such that the seismic data are represented by the resulting wavelet coefficients in the wavelet domain. One then estimates the noise level of the wavelet coefficients, computes a proper threshold value based on the estimated noise level, and retains the leading wavelet coefficients above the threshold, but sets to zero those below the threshold. Finally, the retained leading wavelet coefficients are used as the data in history matching. Since the influence of a wavelet basis on the representation error directly depends on the amplitude of the corresponding wavelet coefficient, the thresholding strategy can substantially reduce the data size, while preserving the information content of the seismic data as much as possible. In addition, as the noise level of the wavelet coefficients is estimated in the course of choosing the threshold value, data uncertainty quantification (in the wavelet domain) is obtained as a natural by-product of the sparse representation procedure, which is a nice feature from the perspective of history matching.

Using the proposed new seismic history matching framework (Figure 1(b)), Luo and his colleagues at IRIS have conducted proof-of-concept studies in both a 2D Norne field model (Luo et al., SPE Journal, 2016) and the 3D Brugge benchmark case (Luo et al., ECMOR XV, 2016), and they showed that the proposed new seismic history matching framework (Figure 1(b)) works very well. For instance, in the 3D Benchmark case (Luo et al., ECMOR XV, 2016), the original seismic data size is around 7 million. Through the wavelet-based sparse representation procedure, the number of leading wavelet coefficients - as the data in history matching - can be reduced to around 1700 (more than 4000 times reduction), while achieving reasonably good history matching performance (see Figure 2).

The wavelet-based sparse representation procedure (Figure 1(a)) is independent of the history matching algorithms, and can thus be combined with any of them. In general, it can be used for sparse representation of data with spatial and/or temporal correlations. Therefore, it is expected that the sparse representation procedure can be transferred to handle big data arising in other fields like climate, environment, and even health and care.

LARGE SCALE POLYMER SHEAR DEGRADATION TEST

BY SIV MARIE ÅSEN AND ARNE STAVLAND

Figure 1 showing the test site for the large-scale test (photo: Siv Marie Åsen)

Polymers are long-chained molecules composed of thousands of small repeating units (monomers). In oil recovery, certain types of polymers can be added to the injected water to make the water more viscous. This allows the injected water to displace the oil in a more favorable manner. The oil will be produced faster, the water breakthrough will be delayed and less oil will be bypassed.

When a polymer solution is flowing, the long polymer chains align themselves with the direction of the flow. But should the solution for some reason be accelerated, the polymer molecules are stretched. If they are stretched too long, chemical bonds in the polymer break. This is known as shear degradation/mechanical degradation. The polymer chains will thus be shorter, which leads to lower viscosity of the polymer solution and a less favorable displacement of oil.

During mixing, pumping and injection, the polymer solution is exposed to several regimes with a potential for degradation. For instance, when it is pumped through valves/chokes to regulate the injection pressure, the conventional method is to choke the stream by imposing a narrow restriction leading to acceleration of the solution.

Since it is of importance to have the correct injection pressure The National IOR Centre of Norway, Halliburton, SNF and IRIS in October 2015 performed a large scale test where several choke concepts where tested regarding to mechanical polymer degradation (see Figure 3). Polymers with different chemical composition were diluted in saltwater to different polymer concentrations.

This revealed three possible ways of choking the polymer solution to desired pressure without harming it:

- The pressure drop is induced over a long distance by pumping it through a coiled tube where the diameter is wide enough to avoid harmful acceleration and long enough to induce sufficient pressure drop (see Figure 2).
- The pressure drop is obtained by placing several conventional choke valves in series with a low pressure drop below a critical value for each of them.
- A concentrated polymer solution is pumped through the choke valve and diluted to desired concentration after the choke. There are two reasons why the polymer is less degraded this way. One is that the choke can be more open and give the same pressure drop when the solution is more viscous. The other is that the polymer molecules are shielded by each other from shear degradation in a more concentrated solution. The shielding effect is proven, but not fully understood.

During the test is was also proven that mixing at large scale (several cubic meters) produced the same viscosity as mixing at the smaller laboratory scale (in the liter-range) and that the

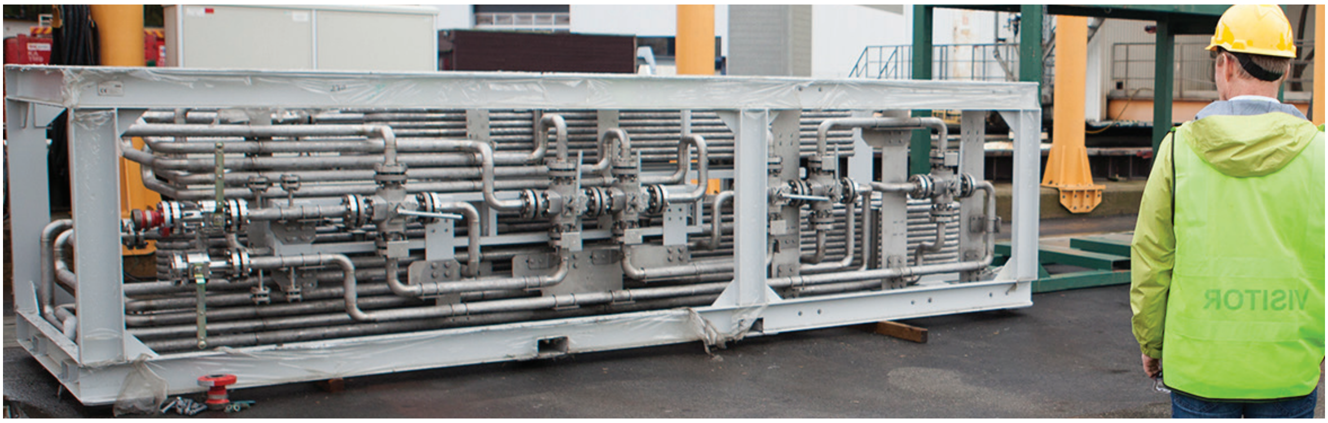


Figure 2 showing SNF's choke concept for reducing pressure without harming the polymer solution. (Photo: Mari Løvås)

difference in polymer degradation for the different kinds of polymers tested where the same as what was expected from laboratory tests.

Laboratory tests of shear degradation of polymers are often performed in capillary tubes (tubes with internal diameter of 0.1-1 mm and injection rates up to 100 ml/min). In 2016, an extensive study was performed to compare results from laboratory with results performed at large scale (internal diameter 0.8-3.5 cm and injection rates from 70 to 600 liter/min). When comparing the two scales, different flow regimes has to be accounted for. In the capillary tubes, the flow is laminar and at large scale the flow is usually turbulent. To check if the degradation of polymer is guided by the same mechanisms during laminar and turbulent flow the mechanical force (the shear) the solution is subjected to was calculated. This is relatively straightforward for laminar flow, but more complex for turbulent flow. We were able to show that mechanical degradation for a given polymer system follows the same dependency on shear, whether the flow is turbulent or laminar (see Figure 3). This was further substantiated by constructing a new set-up for performing intermediate scale experiments where mechanical degradation was performed both at laminar and turbulent flow (internal diameter of 1.75 mm and injection rates from 0.7 to 5 liter/min).

In the oil reservoir, the polymer is also subjected to forces that can degrade it. The forces can be chemical, biological or mechanical. The mechanical forces are caused by the acceleration of the polymer when it is pushed through the narrow pore throats connecting the large pores of the oil bearing porous rock or sand that is the oil reservoir. This type of mechanical degradation is guided by the same mechanisms as degradation in capillary tubes and choke valves, but instead of going through only one constriction, the individual polymer molecule moves through numerous. The forces the polymer is subjected to will be largest in the near wellbore area, as the velocity is highest near the injector.

At laboratory scale, the degradation of polymer in porous media is tested by injecting the polymer solution linearly through a cylinder shaped porous rock sample or sand pack with diameter of a few cm and length of 5-30 cm. It is believed that degraded polymer is less prone to further degradation compared to not degraded polymer, as shorter polymer chains degrades less compared to long chains.

To prove that laboratory scale experiments are sufficient to capture the effect of the numbers of constriction the polymer moves through in an oil reservoir, The Halliburton/IRIS team has in 2016 worked on planning the next large scale test. Requirements to and availability of the equipment has been

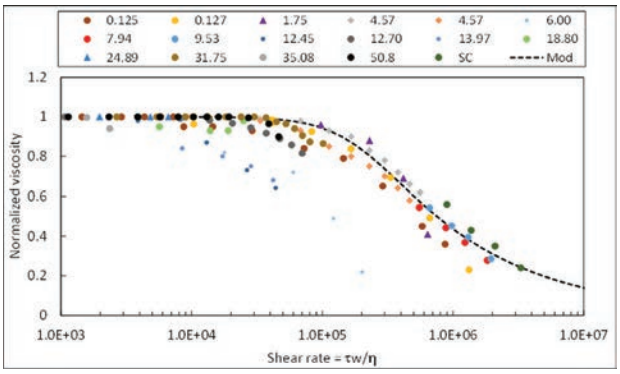


Figure 3 showing how degradation scales with shear rate in tubes with different internal diameter (in millimeter) when turbulence is accounted for. Data points both from this study and from literature (ref; Stavland 2016).

investigated, and what are the most pressing issues to address has been discussed with the partners in the Centre. A plan for performing a large-scale test with sand packs in 2017 is taking form. The sand packs can be up to 12 m long with internal diameter of 20 cm. This test, together with well-designed laboratory tests, will show if the mechanical degradation caused by the porous media will just have to be taken into account in the near wellbore area, or if it will accumulate through the reservoir. It will also indicate how large the system for testing mechanical degradation of polymer solutions has to be to qualify the polymer system for field use.

The possibility of including the use of tracers, different temperatures, sand packs off assorted lengths and set-ups that mimic radial flow in the large scale test is currently also being investigated.

References:

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SELECTED IOR METHODS

BY ARNE STAVLAND

IOR mechanisms to produce trapped or unswept oil are combinations of miscibility, viscous-to-capillary forces and mobility ratio. Injection fluids miscible in oil or yielding ultra-low interfacial tension have the potential to produce capillary trapped oil and to improve the microscopic sweep efficiency. At field scale macroscopic sweep efficiency is at least equally important and addresses methods capable to alter the mobility ratio. Optimized, superior IOR methods are those that at low cost without involving hazardous chemicals, improve both micro- and macroscopic sweep efficiency.

Photo: Polymer flooding is one of the IOR methods being researched in The National IOR Centre of Norway. (Photo: Elisabeth Tønnessen)

The National IOR Centre of Norway has decided to focus on smart water and polymer as the two main types of IOR chemicals. The main arguments for including smart water injection are that modification of the ion composition is technically relatively simple, is environmentally friendly, has demonstrated some IOR potential but without fully understanding the mechanisms. However, the likely mechanisms are related to wettability alteration. In addition, other IOR mechanisms may benefit from combinations with smart water; lowering chemical concentrations, improve the chemical stability and make it possible to utilize alkaline flooding offshore.

Polymer flooding is a frequently applied IOR method and the IOR mechanism is understood by improved mobility control through increased viscosity of the injected fluid. A promising IOR polymer dissolves easily in the injection water, maintain its molecular weight through turbulent flow from mixing at platform and into formation, yields in-depth mobility reduction and improves sweep efficiency. Some of the challenges are how to deal with the flow of non-Newtonian fluids. Synthetic IOR polymers are susceptible to mechanical degradation when passing through flow restrictions, such as choke valves or narrow pore necks in the porous media. Flow behaviour in porous media deviates from flow of water; a fraction of

Comment from the industry:

«Statoil has a good cooperation with IRIS regarding development and use of Sodium Silicate for in-depth water diversion. The cooperation has been important for the development of method and design of field operations. The outcomes of the cooperation have been conduction of a small scale test on a Snorre well in 2011 and a large scale test on Snorre in 2013. Statoil (as the operator) together with license partners on Snorre provided the reservoir segment model, operational data and the measured response data from the field pilot to NIOR.»

Kjetil Skrettingland
Project leader for Snorre In-depth Water Diversion Project
Statoil

the volume in the porous media is inaccessible for polymer to flow, either because of pore space less than the polymer size or depleted polymer concentration close to the rock surface. As a consequence the polymer flow velocity is higher than that of water. However, retention at the rock surface partly counterbalanced this effect. Retained polymer in the porous media give rise to reduced permeability. In terms of mobility reduction, increased water viscosity and reduced permeability have similar effect. For large well distances, the residence time in the reservoirs may be several years. Not all polymers are chemically stable from injector to producer, especially at high reservoir temperature and salt water. Rapid polymer degradation will obviously lower the IOR potential. On the other hand, if controlling in-situ degradation the production of produced polymer is omitted. Therefore, one of the main tasks in this program is to develop models to better predict the IOR.

It is detrimental to understand the mechanisms at core scale and to have access to a core scale simulator that is capable to handle the different IOR mechanisms. IORCoreSim is such a tool and further development and use of the model is a central part in this task. One example is where we used data from a previously performed field pilot on deep diversion by sodium silicate. This allow us to improve the model and to make better predictions for the IOR potential.

To understand the IOR mechanisms at core scale make the upscaling to field scale simpler. However, there are situations where large-scale experiments sometimes are important, either because of questionable physics, or for demonstration or to more reliable pilot decision-making. One example is the potential of mechanical degradation of polymer during mixing, pumping through kilometers of flow lines or through flow restrictions such as choke valves. The results from such a large scale test at flow rates at 400 L/min and flow length up to 400 m was comparable with capillary tube experiments at flow rates about mL/min. The controlling parameter was here the Reynolds number, turbulent to laminar flow.

Another project focuses on the inclusion of IOR in conjunction with Special Core Analysis (SCAL) work. The motivation is that if we are able to define IOR potential early, in order to influence the field development plan. Costly platform modification at a later stage can then be avoided, or no longer be a show stopper. We have demonstrated alteration of fractional flow curve in a steady-state flood experiment by switching from brine to polymer as well as wettability modification. We foresee these type of experiments as excellent in demonstration of IOR potential. In addition, the experimental data are used as input for simulation models.

In one project on nanoparticles we focus on metallic nanoparticles that catalyst subsurface refinery, lower the mobility ratio and produce the oil more effectively.

There are several examples of poorly designed IOR field treatments due to incorrect IOR potential, often because screening tests at lab scale conditions that did not fully reflect the field conditions. This is especially important for IOR fluids involving some sort of wettability alteration. Therefore, one of the projects aims to mimic the reservoir wettability in core scale experiments better. Correct wetting conditions are in fact, for some IOR fluids more important than in SCAL experiments. The reservoir engineer can easily adjust the SCAL derived relative permeability curves to match the history, while the IOR decision is to be based on the available information at the time of decision. The decision on water injection in Ekofisk is an example were the current state-of-art concluded on no significant IOR potential. However, results from a field pilot demonstrated a large potential, with the conclusion on field implementation of water injection, tripled the recovery factor and revisions of laboratory procedures. Similar cases may well exist, where the IOR potential has not yet been released.

THE UPSCALING TOOL IORSIM

BY JAN SAGEN, JAN NOSSEN, TERJE SIRA AND AKSEL HIORTH

The oil and gas industry has always applauded using "standard" reservoir simulation tools. The reason for this is twofold: It is efficient to employ standard workflow procedures, and it is beneficial to apply software which has been qualified on the field scale. With this in mind, our run towards establishing software coupled to standard reservoir simulators started 25 years ago. The vision was to improve and extend reservoir modelling tools without actually changing the reservoir simulator itself. In 1991, the tracer research at IFE had already been ongoing for many years. This is a great success story in itself, but this is another story. Developing a tracer simulation module coupled to a standard reservoir simulation tool then became one of the key tasks within the IFE Tracer Club. A prototype version of this software was established in 1992, exactly 25 years ago. The computer code was written in FORTRAN 77 on a Sun workstation with mouse driven user interface and Unix operating system. The tracer module was able to track species throughout the reservoir, but no chemical reactions were taken into account. The species advection (flow) was performed on a separate grid, which might be finer than the original reservoir simulator grid.

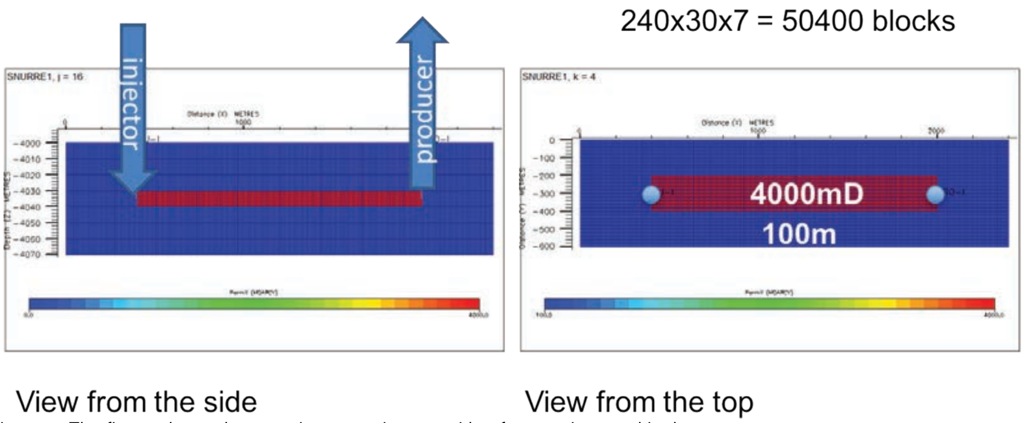

Figure 1: The figure shows the generic reservoir case with a fracture imposed in the system.

Though based on the same underlying concept, IORSim includes chemical reactions and applies improved numerical techniques that make the coupling with chemical species and chemical reactions very effective and accurate. It utilizes modern programming tools as C++ and Python scripting.

In 2015, the main focus of the IORSim project was to test and verify on the field scale the two-way coupling between Eclipse and IORSim including a geochemical module. In 2016 the main focus was to implement a silicate module in IORSim and test it on a generic field case "Snurre". In addition, the back-coupling algorithm with Eclipse has been rewritten in the Python script language and largely improved with respect to stability and efficiency. In this work we have had expert help from Jarle Haukås in Schlumberger.

Sodium silicate injection has proved to be a very promising method for deep reservoir diversion of water. As a result, the volumetric sweep in the reservoir can be greatly improved. We have also performed a more detailed study on how refined simulation time steps affect the results. The next two graphs show the daily oil and water production from the "Snurre" idealized silicate injection case plotted against the cumulative water injection volume for different numerical time steps. We see four phases in the injection:

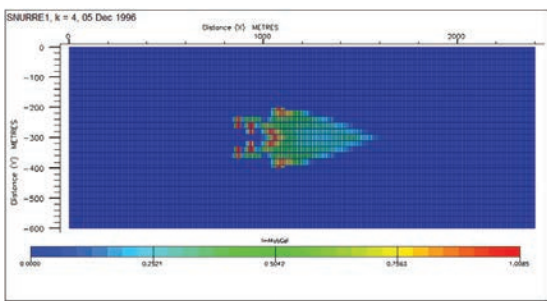

Figure 2: The above figure shows the sodium silicate gel in the reservoir after treatment.

Comment from the industry:

«Upscaling of chemical flooding experiments representing the full field potential is still a challenge in the industry. The existing commercial industry simulators addresses very poorly the many of the complex EOR processes. IORSim has the potential to bridge the gap between laboratory results and the full field potential.»

Steinar Kristiansen
Subsurface Manager
Wintershall Norge AS

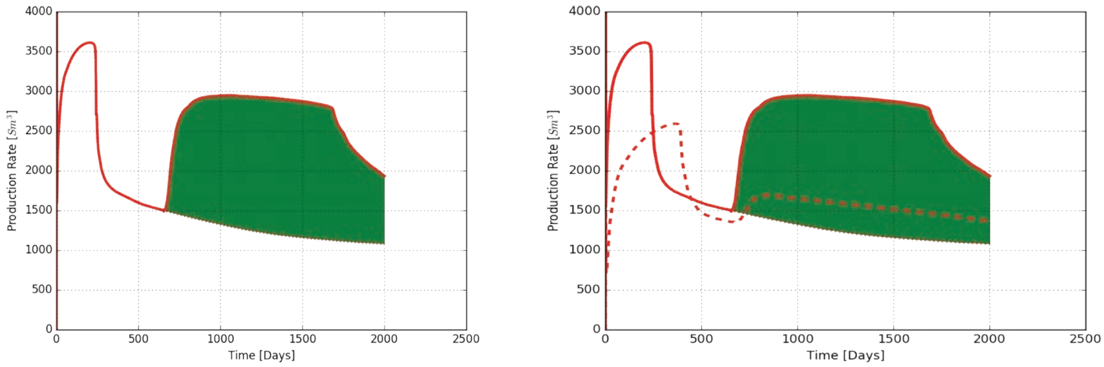

Figure 3: The green area to the left shows the increased oil recovery after silicate injection when 240x30x7 grid cells are included in the Snurre case. The dashed line to the right indicates the increased oil recovery when 60x15x7 grid cells are included. Hence the predicted IOR effect is seen to be quite sensitive to the simulation grid. This will be more thoroughly studied in the 2017 IORSim project. The conclusion so far is that the IORSim - ECLIPSE coupling works well, and that the full potential of this technology should be explored further by performing simulations on realistic field cases.

Figure 4 shows the daily oil and water production from the «Snurre» idealized silicate injection case plotted against the cumulative water injection volume for different numerical time steps. We see four phases in the injection:

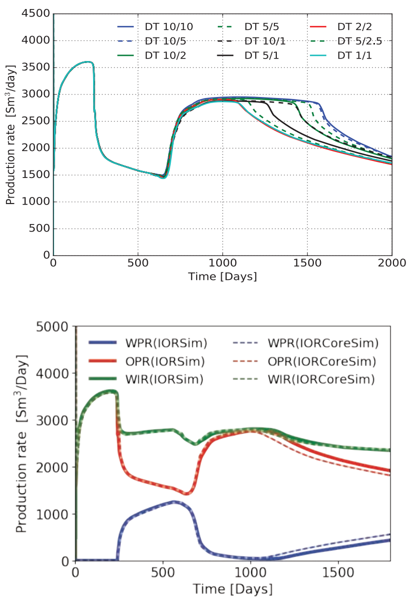

Figure 4 compares IORSim and IORCoreSim.

- Up to about 800,000 m^3 of injected water, the oil production is increasing, and there is no water breakthrough. At the end of this period, the oil production peaks at about 3600 m^3/day.
- At a cumulative injected volume of about 800,000 m^3, water breaks through, and the water production increases rapidly until it reaches a peak of about 1300 m3/day at a cumulative injection volume of 2,000,000 m^3. At this point the oil production has declined to about 1500 m^3/day.
- At this point, the silicate gel comes into effect quite abruptly on the reservoir time scale. There is a sharp drop in the water production rate, and a corresponding jump in the oil production rate.
- After some time, the diverted water has travelled around the silicate gel zone and reaches the production well. The water production resumes and grows almost linearly, while the oil production gradually decays.
- We are also investigating sodium silicate injection in a more heterogeneous case.

Remarkably, the computed oil and water production rates are nearly independent of the numerical time step during the first three phases (before water breakthrough, during water production and after gelling). In the fourth phase, where water production resumes, the results are highly sensitive to the numerical time step. In particular, the time of onset of the second water breakthrough is highly sensitive to the simulation time step.

In the two charts we are able to compare the effects of reducing the time step both in the Eclipse and IORSim simulations as well as only in IORSim. In the legend, "DT 10/5", for example, denotes a numerical time step of 10 days in Eclipse and 5 days in IORSim, and so on. We see that the shorter the time step, the earlier the second water breakthrough occurs, and the earlier the oil production starts declining. We also see that there is a marked effect of decreasing the time step in IORSim alone, but that decreasing the time step in Eclipse and IORSim simultaneously has a stronger effect. This suggests that the time step should be selected with caution and that simulating the silicate injection process using too long numerical time steps may lead to overly optimistic results regarding the cumulative oil production.

CORE PLUG PREPARATION PROCEDURES

BY INGEBRET FJELDE

- Preparation of representative conditions in laboratory flooding experiments

Rock samples from the oil reservoirs are brought to the laboratory to determine key properties of the rock and flow properties. In the laboratory experiments, conditions representative for the oil reservoir should be established to give reliable input to estimation of recovery potentials. Sea water is injected in most of the oil fields on the Norwegian Continental Shelf (NCS), and is then the reference for the Enhanced Oil Recovery (EOR)-methods. If the estimate potential of the water flooding is wrong, the estimated potentials for the EOR-methods will also be wrong.

Core plug preparation procedures are very important for the estimated potentials of water flooding and EOR-methods. Two examples from the NCS can be mentioned where core flooding experiments have contributed to wrong estimates of the water flooding potentials and thereby also to wrong estimates of the potentials of EOR-methods. For the Gullfaks field the residual oil saturation after water flooding was incorrectly determined to be high, and the technical potential for surfactant flooding was therefore estimated to be too high (Maldal et al. 1998). When these first estimates were determined, the understanding was that reservoir sandstone rocks should be water-wet. If the core plugs were not water-wet, the core plugs were cleaned until they became water-wet (Fjelde et al., 2015). Surfactant flooding was not implemented in the Gullfaks field for several reasons, and this has in retrospect turned out to be a correct decision. The potential for water flooding of the Ekofisk formation in the Ekofisk field was first incorrectly determined to be low (Sylte et al., 1988). The less favorable laboratory results compared to the field results might have been due to deposition of wax from the Ekofisk oil in the experiments at room temperature and thereby wettability alteration. Today water flooding has successfully been implemented in the whole Ekofisk field. If the final conclusion had been based on the first estimate, the income from the oil production in the Ekofisk field would have been much lower. These examples show how important the procedures for core flooding experiments are for the potential evaluations.

The objectives for the first phase of the project "Core plug preparation procedures" have been to evaluate standard procedures for preparation of reservoir core plugs to identify critical steps and to work out a proposal for the next phase of the project. This has been done using the experience in the IRIS Petroleum laboratory.

The state of the reservoir rock samples will change during sampling, contamination and storage. Both pressure and temperature are reduced during retrieval of reservoir rock samples. This will alter the rock and fluid properties, e.g. the solubility of minerals and wax deposition can alter the wettability conditions. A gas phase will also be evolved when the pressure is reduced below the bubble point. Invasion of mud/coring fluid during coring can also alter the rock properties. In the laboratory conditions representative for the reservoir should be reestablished.

Information about the compositions of rock, reservoir fluids and mud/coring system (and other possible contaminations) are important input to selection of optimum core plug preparation procedure. It is important to remove precipitates and contaminations with the potential to affect the flow conditions, otherwise, ideally, these core plugs should not be used. The first step should therefore be to determine whether the core plugs are contaminated. Adsorption of mud components can change the wettability conditions. Invasion of particles, polymer and resins from the mud can also reduce the permeability of the rock. The ionic composition of the brine in the mud system is also different from the formation water (FW) composition. The surface properties of the minerals can therefore be changed due to mud or mud filtrate invasion.

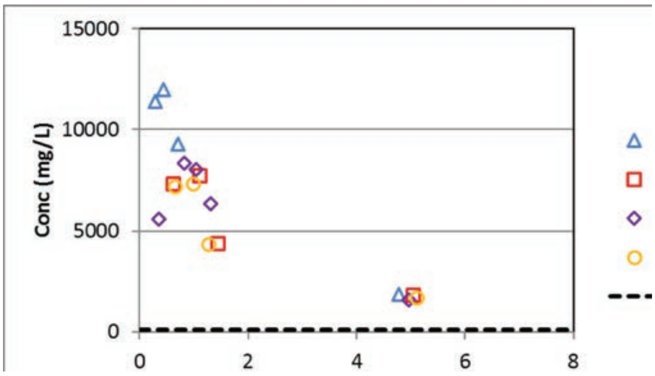

Figure 1 Effluent potassium concentration during injection of SFW injection to reservoir core plugs (Fjelde et al., 2015).

Comment from the industry:

«Understanding relative permeability and wettability is essential to understand waterflood recovery and where the remaining oil is located. The main input comes from special core analysis. It is critical that the core is in such a state that it correctly represents wettability and rock properties during SCAL tests. Coring and core preparations is essential to determine both the waterflood baseline and what the recovery potential is for different EOR methods.»

Roar Kjelstadli
Lead Reservoir Engineer
AkerBP

The standard procedure for core plug cleaning can easily be improved by including chemical analyses for detection of contaminations. An example of analysis of effluent concentration is shown in Figure 1 where high potassium concentration was found in core plugs contaminated by KCl-based mud. If the core plugs are found to be contaminated, they should be cleaned until these contaminations are removed. The color of effluent and differential pressure across the core plugs cannot confirm removal of contaminations. The challenge is that the mud systems contain many products of technical grade. A more general method, ideally non-destructive, for determination of the cleaning efficiency should therefore be developed. Contaminations of rock with particles and polymers from the mud can increase the surface area and/or introduce new types of surface area. These components can be very difficult to remove. See image from Scanning Electron Microscopy of cleaned high permeable sandstone in Figure 2.

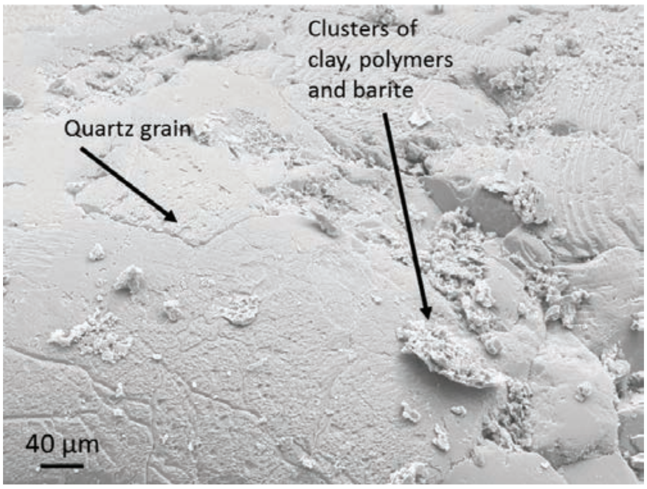

Figure 2 Scanning Electron Microscopy image of cleaned sandstone reservoir core (Fjelde et al., 2015).

The composition of the selected synthetic formation water is critical because it will determine the properties of the minerals in the rock and thereby the established wettability conditions. The composition of reservoir water samples can be contaminated (e.g. during sampling) and can be changed during transport and storage before the chemical analyses. The determined composition of water samples can be corrected for contaminations. Ions of low concentrations are often excluded either because they can increase the risk for precipitation and/or are thought to not be important. It has been shown that this should not always be done. Low concentration of sulphate on the same level as in the formation water, has been reported to give more water-wet reservoir chalk than similar formation water without sulphate (Figure 1) (Fjelde and Asen, 2015). A procedure for selection of stable water composition at test conditions should be developed.

It is important that the crude oil sample is not oxidized and not contaminated by surface active compounds because surface active contaminations can affect the established wettability conditions. Several parameters can affect the wettability conditions established in aging with crude oil, e.g. aging time, volume of crude oil injected and use of white oil for exchange of fluids. Oxidation of minerals will change their surface properties and can thereby also affect the established wettability conditions. Anaerobic conditions prepared by chemical mixtures have been reported to give other initial wettability conditions than aerobic conditions (Rajapaksha et al., 2014). The interactions of these chemicals and their products, with fluid components, minerals and EOR-chemicals should be investigated before this method can be implemented as standard. It is not possible to prepare and

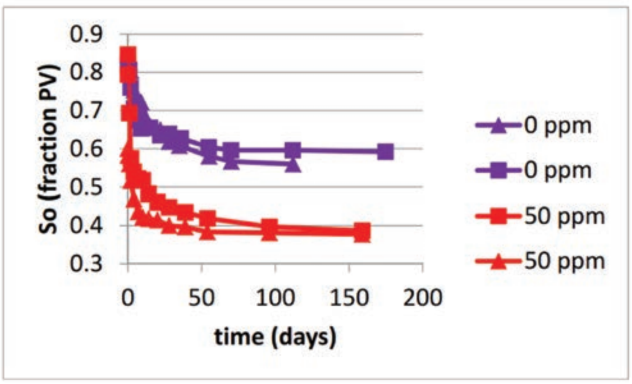

Figure 3 Oil saturation (So) vs time during spontaneous imbibition of sea water into core plugs prepared by using formation water with (50ppm) and without (0ppm) sulphate.

Photo: Centre Director Merete Vadla Madland and Ingebret Fjelde (IRIS). (Photo: Elisabeth Tønnessen)

maintain anaerobic conditions by using standard procedures for Special Core Analysis (SCAL) and EOR core flooding experiments. A preliminary study of the effects of oxidation on the wettability of a clay mineral found in reservoir rock, will be reported in 2017 (Fjelde et al., 2017).

Reliable core preparation procedures are important in the investigation of EOR mechanisms and determination of the potentials for EOR-methods in The National IOR Centre of Norway. It is recommended to investigate the most critical steps in preparation of core plugs for SCAL and EOR-studies, e.g. cleaning efficiency, selection of synthetic formation water composition, oxidation and aging process.

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RESERVOIR SIMULATION TOOLS 2016

OPM (Open Porous Media, http://www.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 of Norway, 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 2016 task 6 activities have focused on improving the standard discretization methods in OPM used for IOR related simulation activities. When dealing with transport processes of chemically active species it is very important to employ discretization methods of higher order accuracy. While such methods have been studied for quite some time these methods are still under represented in application codes used to assess reservoirs for IOR potential. Task 6 has contributed significantly to improve OPM in that direction. The Figures show two examples of higher order methods employed on relevant test cases.

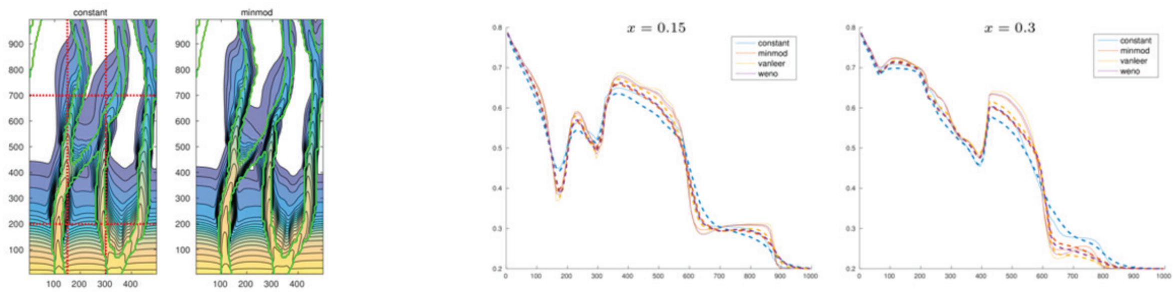

Figure 1: Polymer flooding in a channel using different discretization techniques. The channel pictures show the polymer concentrations for the low order method (left) and higher order method (right). The graphs show the solutions along the red dotted lines for a fixed x-coordinate and the colors represent different higher order methods compared to the low order method (blue line). One can clearly see the superiority of the higher order methods and a significant reduction of smearing effects is discovered. The full study is available in Lie, Mykkeltvedt, Raynaud: Fully Implicit Higher-order Schemes Applied to Polymer Flooding. ECMOR XV, 2016.

Comment from the industry:

«The Open Porous Media (OPM) initiative highlights the benefit that an open software framework can bring to the progress of modern reservoir simulation technology. Software programs, from simulator to upscalers, are developed under GNU General Public License (GPL) software by a growing and open community of mathematicians and reservoir engineers. I think that people in oil companies and, more generally, engineer/scientists interested on porous media problems will benefit from the possibility of a rapid transfer of new ideas into tools that can be used to solve real problems without limitations or delays due to commercialism. Benefits can be huge also from an economic point of view.»

Alberto Cominelli
Reservoir Modelling Technical Advisor
Eni SpA

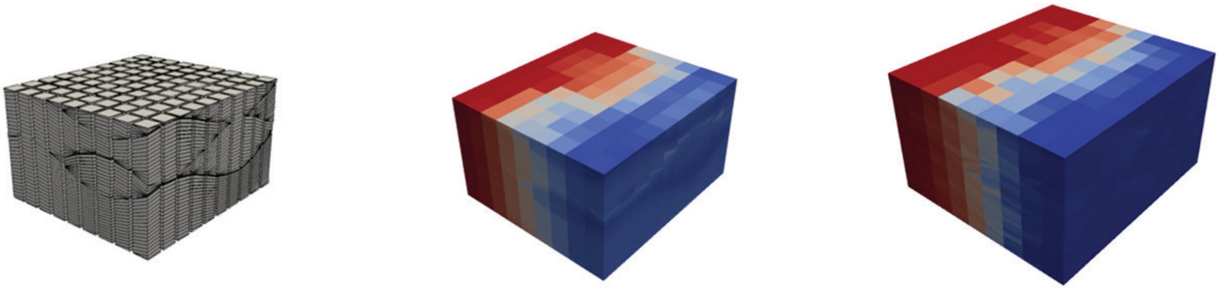

Figure 2: Comparison of low and higher order schemes for transport in reservoirs. Left the reservoir grid is shown. The middle figure shows the low order method and the right figure the higher order method. The higher order scheme shows reduced smearing of fronts. The full study is available in Klöfkorn, Kvashchuk, Nolte: Comparison of Linear Reconstructions for Second Order Finite Volume Schemes on Polyhedral Grids. ECMOR XV, 2016.

DOUCS - DELIVERY OF AN UNBEATABLE CORE SCALE SIMULATOR

BY ARILD LOHNE

The objective of the project is to develop a tool for improved simulation of IOR-processes at the core scale. The simulator IORCoreSim is built to handle SCAL (Special Core Analysis) and various IOR type core flood experiments. Several IOR methods can be simulated in core-scale models and small field-scale models. This makes IORCoreSim a tool for improved interpretation of laboratory experiments and for scaling of involved mechanisms to the field scale. The main benefit is better control of IOR processes and reduced uncertainty of field implementations.

A main part of the work in 2016 has been on testing the code by simulating various experiments, correcting bugs and adding minor improvements. This involves experiments of e.g. types polymer injection[1] (see Figure 1 and Figure 2) and spontaneous imbibition (see Figure 3).

Several new options/improvements implemented the last year have increased the flexibility of the simulation tool. The silicate gel model implemented in IORSim[3] was implemented so that IORCoreSim could be used for comparative simulations and validation of the methodology used by IORSim (add-on tool to Eclipse). Some new options that are of general value for several IOR methods include models for tabular and kinetic adsorption, improved model for the effect of permeability and saturation on molecular diffusion and added mass balance calculations for volume in spontaneous imbibition cell and the possibility for simulating cell flow through.

The IORCoreSim simulator is gradually being used more in spin-off projects. Examples of that are the use of IORCoreSim for interpretation of special scale inhibitor experiments (COREC project), for examination of the effect of composite core in SCAL experiment[4] and in education[5].

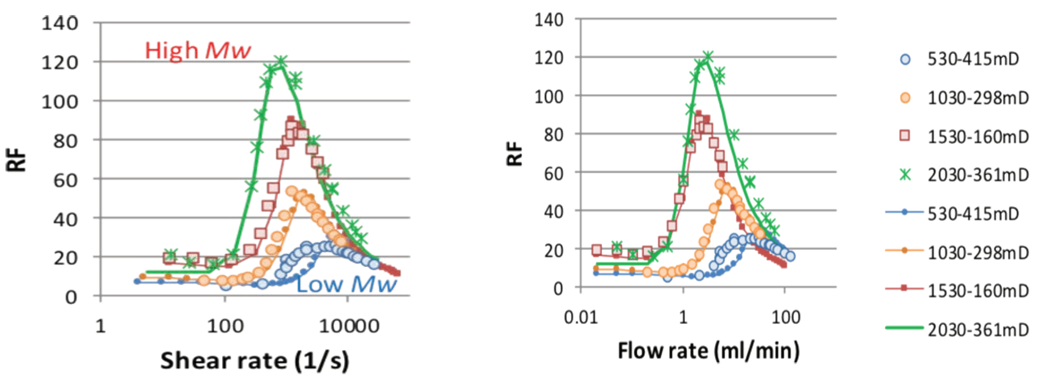

Figure 1: Resistance factor RF from injection of 1500 ppm HPAM (hydrolyzed polyacrylamide) through 7 cm long core plugs at increasing flow rate. Effect of HPAM molecular weight. Replotted from data in ref. [1]. $RF=\Delta p_{polymer}/\Delta p_{water}$.

Comment from the industry:

«When designing an EOR project, our understanding of the displacement process and the achievable incremental recovery relies quite heavily on core scale SCAL experiments performed in the laboratory. Because the laboratory scale SCAL experiment is only partly able to mimic how displacement processes behave in the field, simulation of the lab experiment is essential in order to understand how the process might behave in the field. For advanced EOR methods it is essential that the simulation captures the physics of the process in a meaningful way and here the DOUCS software gives us a distinct benefit because key physical mechanisms of polymer and smart water flooding are modelled properly by the code. This helps reducing the uncertainty when upscaling lab results to the pilot and field scale.»

Niels Lindeloff
Lead Reservoir Engineer
Maersk Oil

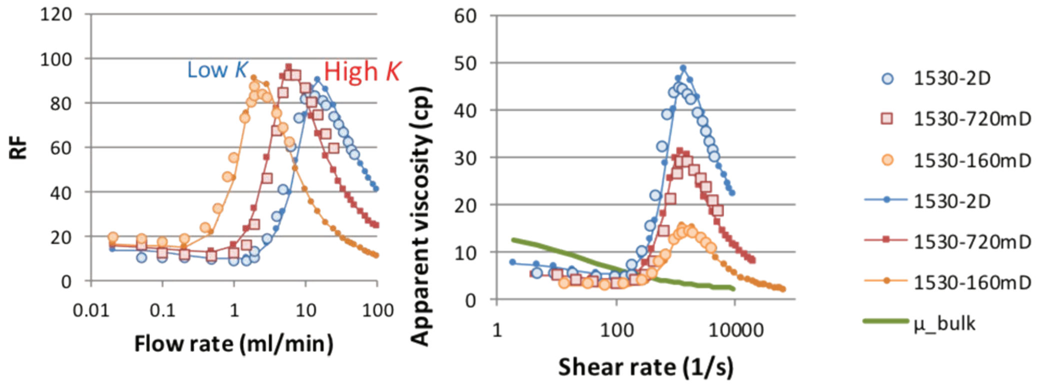

Figure 2: Resistance factor RF from injection of 1500 ppm HPAM (hydrolyzed polyacrylamide) through 7 cm long core plugs at increasing flow rate. Effect of permeability. Replotted from data in ref. [1].

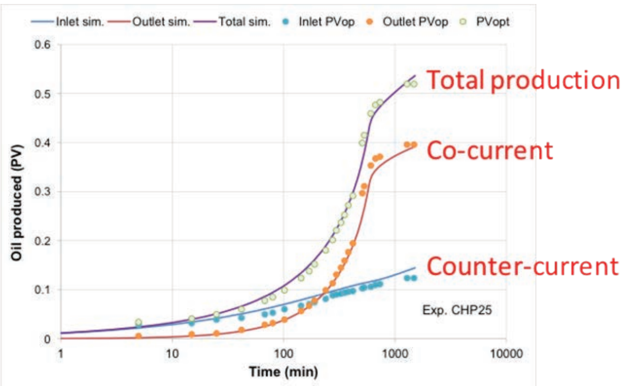

Figure 3: Spontaneous imbibition in chalk core experiment from ref. [2] with viscous oil (83 cp) and two end faces open for flow, inlet end exposed to water and outlet end exposed to oil. Figure shows simulated (lines) and experimental (points) counter-current oil production at the inlet end and co-current production at the outlet end.

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FORCES KEEPING CHALK TOGETHER

BY ANDERS NERMOEN, REIDAR INGE KORSNES, IDA LYKKE FABRICIUS AND MERETE VADLA MADLAND

FACILITATING RESEARCH

Chalk and limestone reservoirs host significant hydrocarbon – up to 50% of the known oil and gas reserves world wide, and above 30% for the Norwegian Continental Shelf. UiS and IRIS have in cooperation with the COREC-program and ConocoPhillips (CoP), amongst other, focused the research on understanding how fluid-rock interactions affect the way in which oil and water flow through chalks, and how the oil/water composition alters the geomechanical chalk properties. This long-term research focus has since the late 1980s been paramount for developing applied scientific knowledge – useful for the oil and gas industry. An example is a newly developed spin-off project: Permeability in Geomechanics - a COREC project in cooperation between UiS and CoP. That being said, the co-operation with academia would not have succeeded without the existence of curiosity driven basic scientific research. Basic questions such as: "Which forces hold chalk together?"; "Which processes control the elastic parameters of rocks?"; "To which degree does cementation contribute to chalk strength?"; and "How is time-dependent deformation sensitive to pore fluid composition?" are all basic questions with significant applicable importance.

Overall, core experiments performed over the last three decades have shown how chalk mechanics is sensitive to factors such as temperature, stress, deformation/work hardening, time and, most importantly, to the pore fluid composition. Details of how these factors dictate chalk mechanical parameters are, on core level, underway of being mapped out.

STIFFNESS AND STRENGTH

In a recent paper we investigated how the elastic stiffness and yield strength varied for four different seawater-like brines, test temperature (ambient and reservoir temperature; 130°C), and fluid residence time were changed (Nermoen et al., 2017). The results are summarized in Figure 1, where we see that neither pore fluid composition, temperature, nor fluid exposure time (aged/unaged) could dictate stiffness and strength. The cores were not flooded, but were only saturated focusing the attention to the immediate effects of the pore fluids, i.e. how adsorption of surface-active ions affected strength. The aging tests (16 tests) were performed by submerging the cores with the test fluid for three weeks at 130°C and 7 bar. Further analysis showed that a combination of parameters were important to stiffness and strength. Figure 2 display how temperature and aging affect stiffness and strength depends on the different pore fluids. The effect of seawater (SSW) and sodium sulfate brine (Na2SO4) could primarily be understood by adsorption of divalent ions onto the chalk surface at 130°C, which gave rise to electrostatic repulsive forces. These are ideas introduced to the understanding of chalk core mechanics by Risnes et al. (2005) and further developed by Megawati et al. (2013). When divalent ions adsorb onto calcite surfaces this change the diffuse layer from the chalk such that at intermediate grain distances, where these electrostatic layers overlap, a disjoining pressure forms. The overlapping diffuse layer reduces the overall attraction between grains. This effect was checked in an experimental study of the contact forces between two calcite minerals using atomic force microscopy (Røyne et al. 2015). A significant component of the observed strain in triaxial loading experiments are associated with grain reorganization. If disjoining pressure from ion adsorption reduce the normal force between grains, then grain-grain friction is reduced – a governing factor for stability of granular systems.

TIME-DEPENDENT MECHANISMS

In another recent study we investigated how chemical processes affected time dependent creep deformation during continuous flooding of $MgCl_2$ brine. In six 160 days flow-through tests, performed at two temperatures (92 and 130°C) and three effective stresses (0.5, 3.5 and 12.3 MPa), the dissolution of calcite was shown to be dependent on both temperature and stress (Nermoen et al., 2016). As can be seen in Figure 3a, the dissolution of calcium increases with temperature and stress. The stress dependency is only observed for the high temperature tests. As can be seen in Figure 3b, chemical reactions lead to accelerated strain after 25-50 days of flowing for the 130°C test both for the test performed at 3.5 MPa as well as at 12.3 MPa. This observation is significant. It exemplifies the idea that stress play a role in the chemical potential, and that the force network responsible for the mechanical integrity of the chalk is sensitive to dissolution – but

Comment from the industry:

«Continuous Improvement is the philosophy that drives our motivation for still carrying out research on chalk. Recognizing the vast experience, from field data to research activities, gathered through the years for a field like Ekofisk is important for unlocking the potential of extended life in these great but challenging chalk reservoirs. Deployment of new technologies, assisted by research communities around the world, has increased expected recovery from 17% towards 60% for the Ekofisk field. This is what keep Ekofisk the Pioneer among oilfields even after soon 46 years on production. The project Permeability and Geomechanics is another example of this combination of 'standing on the shoulder' of a great legacy whilst aspiring for growing the potential reward in the future to come.»

Edvard Omdal
Senior Reservoir Engineer - Geomechanics
ConocoPhillips

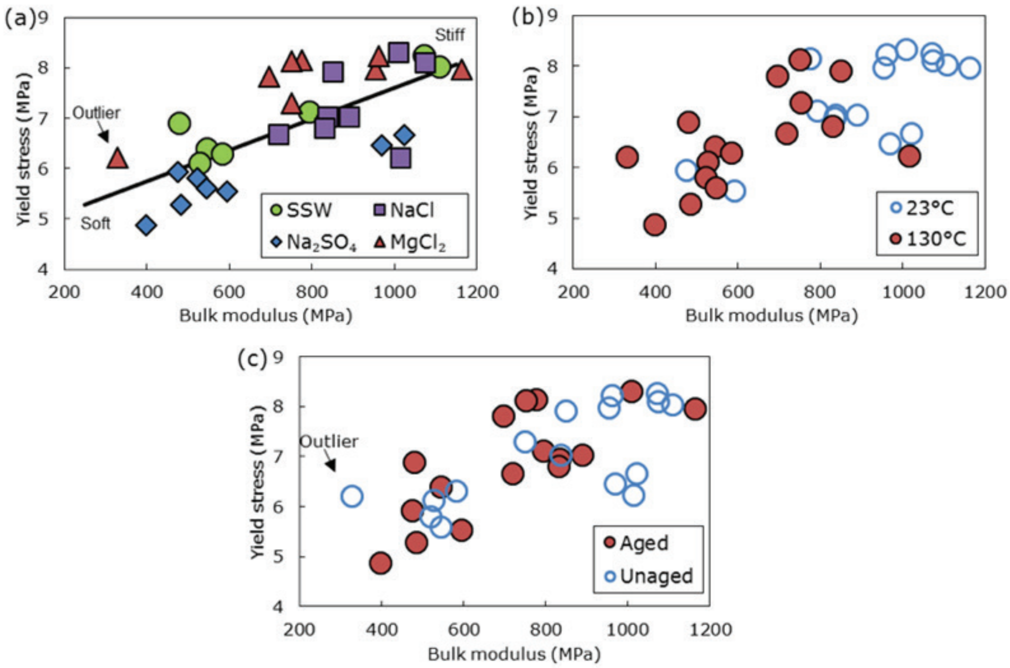

Figure 1: Yield strength and bulk modulus plotted for different (a) brine composition, (b) test temperature, and (c) aged vs unaged. Neither of these parameters dictate univocally stiffness and strength, however, trends can be seen.

only after a certain time. This result was confirmed in another recent publication in review by Wang et al. (2017), demonstrating that accelerated strain during chemo-mechanical compaction is chalk-type dependent. Detailed analysis of the relative proportion overall size and mineral volume changes reveal that the pore volume (and permeability) changes in non-intuitive ways. This is because dissolution-precipitation processes of the bulk volume increase the rate of pore collapse (Nermoen et al., 2015).

THERMAL EFFECTS

The anisotropic thermal expansion coefficient of calcite when heated, calcite expands in one direction and shrinks in the other (Rosenholtz and Smith, 1950). This lead to frustration between closely placed calcite grains when temperature is changed. Repeated temperature variations have shown to induce structural damages to building materials made up of limestone and marble rocks. Would the same effects occur in chalks with equal chemistry, but different micro-structure? In an on-going PhD project funded by The National IOR Centre of Norway, the impact of temperature variation on mechanical property is studied in different chalk types at different degree of diagenesis. We have already shown how the elastic and plastic partitioning during a stress cycle is affected by a

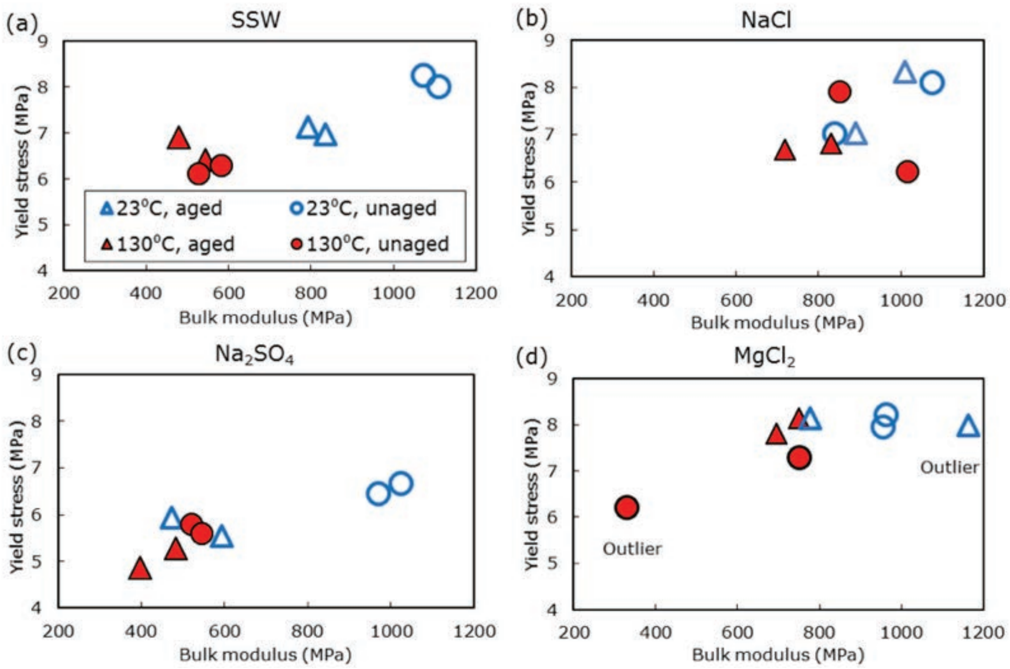

Figure 2: Stiffness and strength for the different brines (a to d). High temperature tests are typically weaker than low temperature and aging affects stiffness-strength.

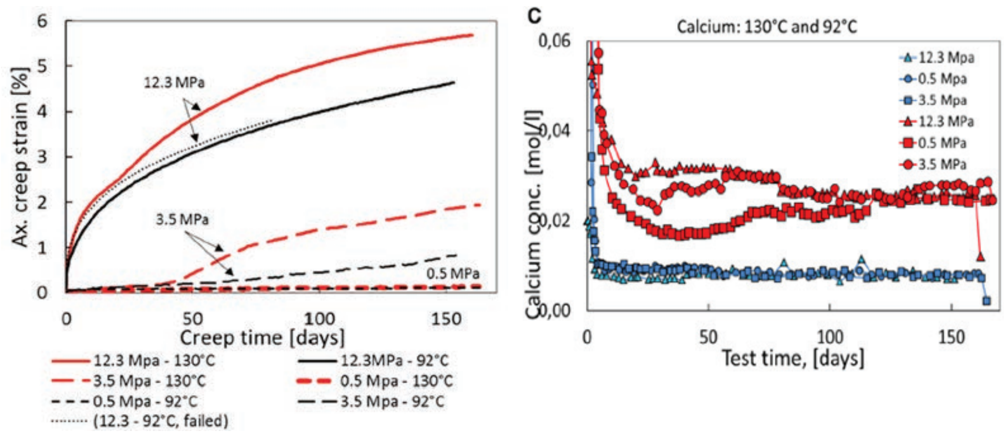

Figure 3: Creep deformation with time for 92 (black lines) and 130°C (red lines). Strain acceleration seen in the 130°C experiments at 3.5 and 12.3 MPa, at 25 to 50 days. (b) Dissolution of calcium with time. Dissolution is larger for the 130°C tests (red) than at 92°C (blue). From 10 to approx. 100 days the produced calcium concentration is larger for the 12.3 MPa tests than 3.5 MPa, and 0.5 MPa.

heat pulse. It was found that the plastic component of the total strain increase when heat is added (Livada et al., 2016). This shed light onto the basic understanding of how strain is accumulated in chalks – information that may be important for predicting how pore pressure buildup affects strain recovery.

TOWARDS A UNIFIED UNDERSTANDING?

During the diagenetic processes from carbonate ooze (muddy upper 2-300 m) to limestone there is an intermediate stage at which porous chalk exists (see Figure 4). During diagenesis, the relative importance of the physical forces binding grains together is changed from purely electrostatic, in one end, to be dominated by intergranular cementation in the other. Chalk can be recognized by the preservation of the coccoliths, foraminifera and algae's shells also seen in carbonate ooze (Fabricius, 2003). The paleonotological fingerprints are less frequently identified in limestone and marble due to its chemical reworking due to time, stress, dissolution/precipitation processes. Despite being weaker than several other rock types, chalk is a competent rock with nonzero stiffness and strengths that can sustain significant stress over time. It is our belief that the mechanical property of chalk is dictated partially by electrostatic forces and partially by contact cement and that the sensitivity to the pore fluid composition is lower for highly

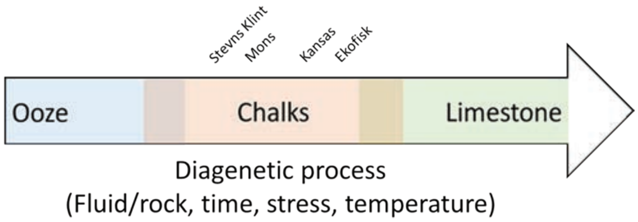

Figure 4: Chalks found within the diagenetic transition between loose carbonate mud (ooze) and competent limestone / marble rock. The different chalks exposures exists at varying degree of diagenesis, dependent on magnitude of rock/fluid interactions, time, effective stress level and temperature. Does the degree of diagenesis alter the relative importance of forces holding chalk together?

cemented chalks than those exposed to lesser amounts diagenetic processes.

EPILOGUE: PUTTING CORE DATA TO USE?

To make use of the experimental results, the obtained knowledge has to be combined with multi-phase flow reservoir models that calculate oil/water saturation, ion transport and temperature through time and space. These models need to include the fluid-rock mechanisms that control ion transport: adsorption / desorption of surface active ions, and dissolution / precipitation from chemical reactions. When the core insights are implemented, we then would generate dynamic spatial maps of how mechanical properties changes during seawater injection. Perhaps the 4D seismic data from Ekofisk South can be at use?

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HUNTING FOR THE PERFECT MOLECULAR COMPOSITION TO DETERMINE NEAR-WELL OIL SATURATION...

BY TOR BJØRNSTAD

Single well tracer push-and-pull technology for determination of near-well S_{OR} has a great potential for improvement. This technology is based on the application of at least one passive water tracer and at least one water-oil partitioning tracer. It involves injection of a reacting tracer, out to a distance of 5-10 meters from the wellbore. The reacting tracer may be an ester molecule which start reaction with reservoir water (hydrolysis) and produce alcohol and acid. Now, there are two scenarios: The ester may itself be a water-oil partitioning compound. In that case, the ester dwelling time in the reservoir is stopped after conversion of about 50% of the ester. At least one of the reaction products is a passive water tracer. Upon back-production the passive water tracer and the remaining ester moves with different speed. Difference in production time is proportional to S_{OR} in the near-well area. The other scenario is that the ester itself is not necessarily a water-oil partitioning compound. However, during hydrolysis the produced acid is a passive water tracer and the produced alcohol is a water-oil partitioning tracer. The rest of the process is the same as described above. This technology, in brief called SWCTT (Single-Well Chemical Tracer Technology), is suitable to measure the effect of an EOR-campaign in the reservoir using a single well.

Existing technology, first developed in the 1970s applies hundreds of barrels of ester solution creating a number of question marks for the method itself. The present project in the IOR Centre will develop a new brand of esters. This allows us to aim at a volume reduction by a factor of 104 -105. Postdocs and research scientists are working on this task.

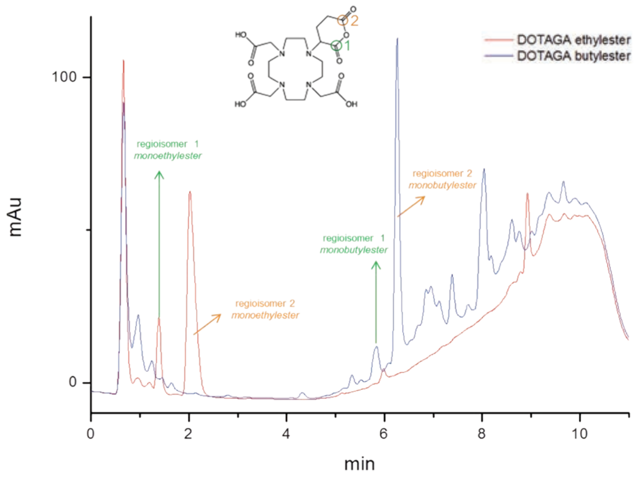


Figure 1: Experimental evidence suggests that this molecule may be an important player in the future SWCTT

Development of new SWCTT tracers is concentrated around chelate complexes of rare earth elements like europeum (Eu), terbium (Tb) and dysprosium (Dy) and their ability to be analyzed in minute quantities by so-called time-resolved laser-induced fluorescense spectroscopy. The complex must contain carboxylic acid groups for the esterification with

Comment from the industry:

«Single Well Chemical Tracer Test is a powerful methodology for residual oil saturation measurement to evaluate reservoir EOR performance at a consistent well scale resolution. This was used by Eni as an intermediate step in the entire EOR workflow to guide multi-well chemical EOR projects and to reduce the associated risks, giving a strong impact on the selection of tertiary field deployments and quantification of reserves. We think that tracer technology has still a big potential for further development and optimization and IFE, as a center of excellence, can sustain and push forward the progress in this field. It was a great opportunity to work closely with IFE and Restrack on two challenging and successful SWCTT applications for EOR performed in two African fields.»

Chiara Callegaro, Reservoir engineer - Eni
Martin Bartosek, Laboratory Technical Leader - Eni

a selected alcohol. Various complexing agents have been tried. A promising compound in focus at present, abbreviated DOTAGA, has a ring structure, which might improve complex stability. It contains five acid groups. The aim is to esterify only one of these groups with high chemical yield, and that is a chemical challenge. Without being too specific here we have lately introduced DOTAGA-anhydride as a precursor for the esterification process. Ethyl- and butyl-esters have been synthesized. Analysis of the reaction mixture by high-performance liquid chromatography coupled with mass spectrometry (UPLC-MS-MS) confirms that identified main peaks in the UPLC chromatogram are clearly related to the monoester compounds (55 % of yield for the monoethylester compound). This is a promising result. We continue work to improve the synthesis, and we have started to assemble parts for a HPLC-based preparative separation and purification system. Such a system will enable isolation of the produced monoester fraction, even for a chemical yield of 55 %.

ON THE SCENT OF NEW OIL DETECTIVES

BY TOR BJØRNSTAD

Measurement of water-contactable remaining oil in swept volumes between wells is based on the simultaneous application (injection) of a liquid pulse containing at least one passive water tracer and at least one water-oil partitioning tracer (so-

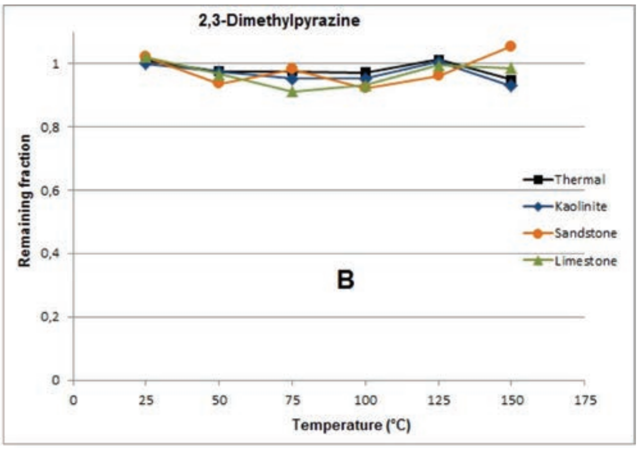


Figure 1: The PhD student believes that the stability of this compound is perfect!

called PITT tracer - Particioning Inter-well Tracer Tests) in an injection well. The first moves through the reservoir towards a production well with the speed of water while the second is lagged behind. The delay of the latter is a function of the oil saturation. Today, only a few molecules are qualified for this purpose and several more are required for application in reservoir sections with several injectors and producers.

A strict requirement for the water-oil partitioning tracer is that the compound forms true molecular solutions in both the water and the oil phases. Hence, any surfactant-like molecule with clearly expressed hydrophilic and lipophilic parts should be avoided. Those would rather monitor the water-oil surfaces instead of the oil volumes. Development of such phase-partitioning tracer compounds is the main task for a PhD student.

Originally, 16 candidate compounds were selected for laboratory testing. One was discarded on an early stage. The full static stability experiments involving the remaining 15 compounds were concluded. The stability behavior appears to be independent of pH but dependent on temperature. Results allowed the selection of 6 of these compounds for further investigation as PITT tracers. 5 of the remaining 9 compounds show potential for determination of temperature in the field, and experimental results fit satisfactorily a developed kinetic reaction model that can be used for such determination. Two compounds are under further investigation to assess the possibility for their use as "clay detectives".

The development of an analytical method based on HS-SPME-GC-MS-MS to identify and quantify the 6 promising PITT tracer candidates in real field samples of produced water proved successful for 5 of the compounds.

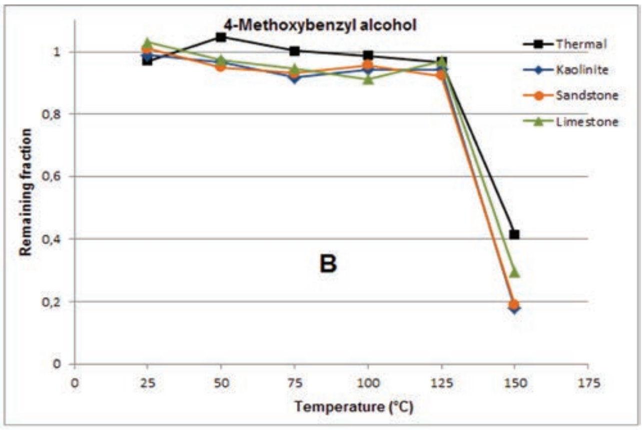


Figure 2: Here is an interesting development, - have we stumbled across a thermal front detective?

FROM PORE TO CORE

BY ESPEN JETTESTUEN, OLAV AURSJØ AND JAN LUDVIG VINNINGLAND

A core sample used in flooding experiments might contain an order of 1013 pores, and it is not feasible to process this amount of information in a pore scale simulation. However, for many processes a lot of the detailed pore information is redundant. For instance, flow in porous media is well described by a single quantity, the permeability, defined by Darcy's equation (volume flux is proportional to permeability times pressure drop). The role of upscaling is then, in reality, to identify the few important quantities that characterize the pore network and influence the fluid flow on the large scales.

The difference in scales not only important for how much detail one can describe, it also dictates what transport mechanisms are important. For chemical flooding, we would expect that molecular diffusion drives the transport of aqueous chemical species on the pore scale, while on the field scale the dominant transport mechanism is fluid advection. Hence, an upscaling procedure consists not only in identifying which geometrical information we need to retain, but also in identifying what processes are pertinent on a given scale.

The IOR-Centre projects range from the sub-pore scale to the field scale. Our workflow is illustrated in Figure 1: the sub-pore scale (left) provide boundary and bulk behavior to the pore scale models. The pore scale models (center) are then used to examine which quantities are important and how they are correlated. These correlations are then compared with core scale experiments (right), and the models can be refined and improved depending on how well they match experiments. A comparison with experiments is also a nice test for our understanding of what physical processes that are important. Hence, a good match with experiments will suggest that we have taken into account the dominating pore scale processes.

To investigate pore scale processes we have to use realistic pore scale geometries in our simulations. The volume of the pore geometry should be large enough to yield the same flow properties as a core scale sample in the lab. Chalks have tiny pores, typically less than 1 micrometer, and this is a challenge when we want to accurately image the pore space. Non-intrusive imaging techniques such as X-ray usually have a lower resolution limit around 1 micrometer which makes them unsuited for chalk imaging. For this reason, we have chosen to use an intrusive technique, FIB-SEM (Focused Ion Beam – Scanning Electron Microscopy), where thin layers of the sample are sliced off one by one.

In collaboration with Dr. Hongkyu Yoon at Sandia National Laboratories (SNL) we have obtained detailed pore geometries of different types of outcrop chalk. The internal pore structure of the samples are imaged layer by layer using a focused ion beam (FIB) to peel off 10 nm thick slices. After each slice, an image (10 nm resolution) of the exposed surface is recorded using an electron microscope (SEM). The stack of gray-scale images is then segmented into regions of black and white to separate the solid volume from the void pores.

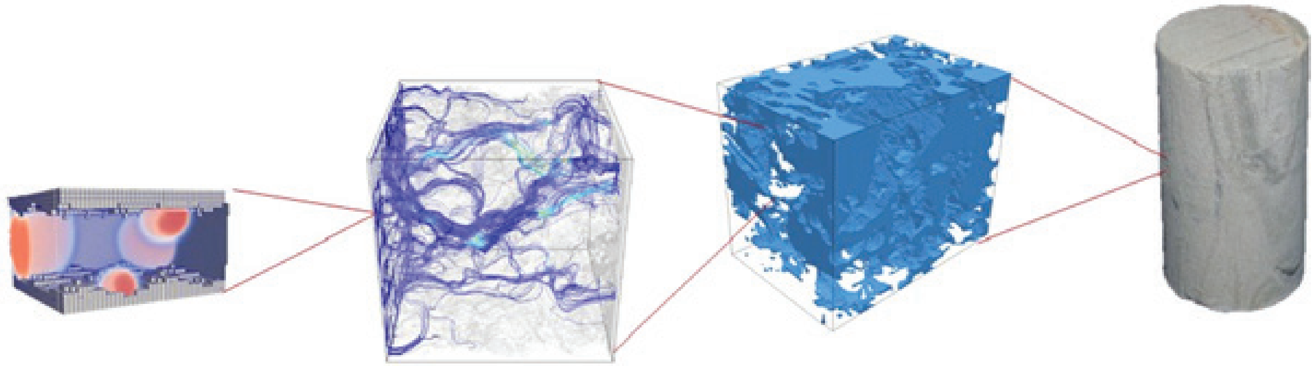


Figure 1: Illustration of the workflow when upscaling from pore scale (left) via Darcy scale to core scale (right).

Comment from the industry:

«The normal way the industry models multi-phase flow in porous media and various EOR methods, is a simplification of the quite complex flow and phenomena happening at the pore scale. While the normal scale within reservoir engineering spans from core to field, it is sometimes necessary to understand what happens on the pore scale, and link this back to the core and field scale. Both physical experiment (e.g. micro-models) and numerical modelling (e.g. pore network modelling and lattice Boltzmann modelling) can be excellent tools to improve the fundamental understanding. My own journey within porous media started at RF (now IRIS) with reservoir modelling, theoretical aspects around special core analysis and multi-phase flow at the pore scale, and this has been a good foundation to meet challenges in the industry.»

Kåre Langaas, PhD
Chief Reservoir Engineer
AkerBP

a) Stevns Klint

b) Kansas

c) Liège, flooded (UU)

d) Liège, unflooded

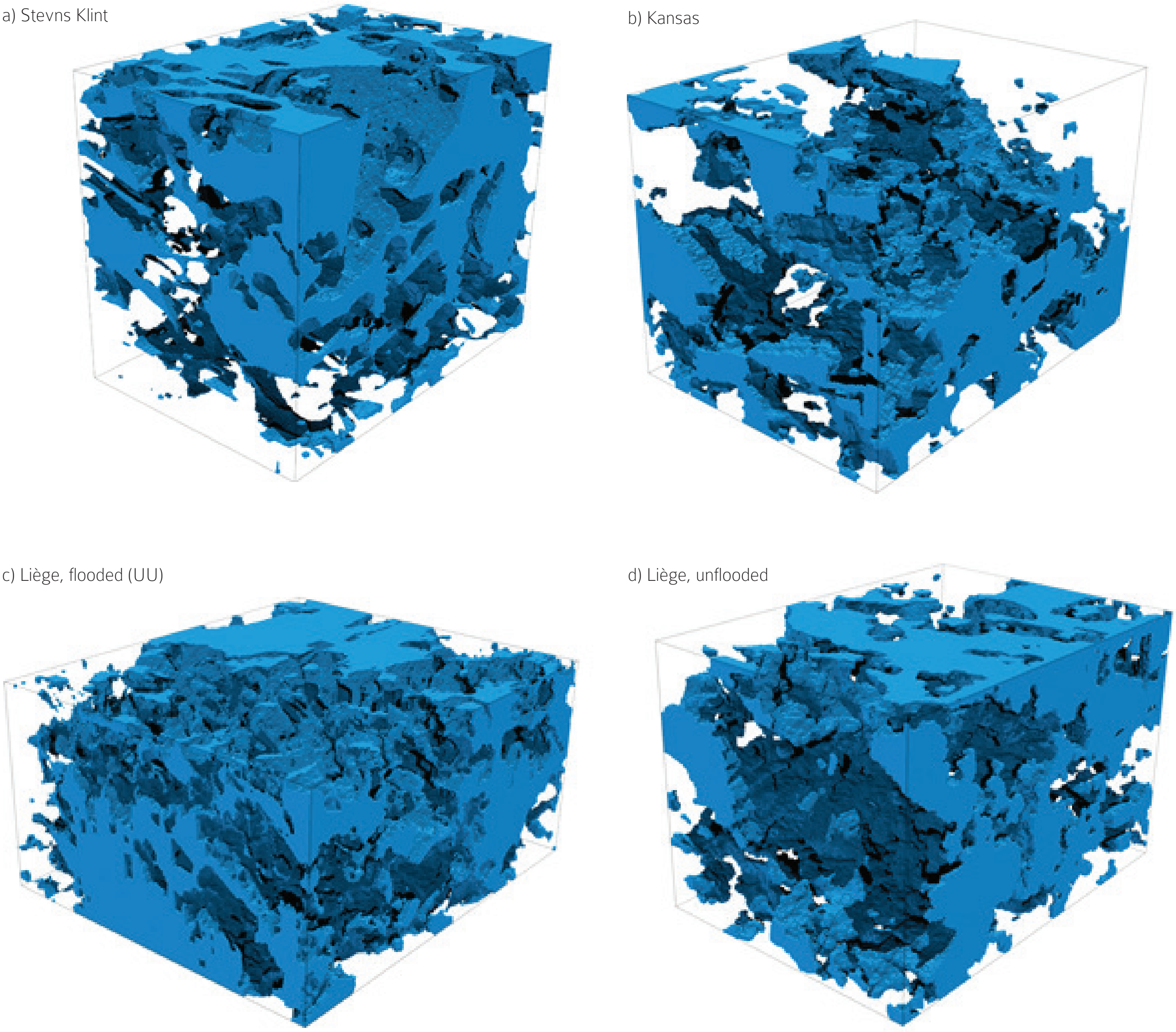


Figure 2: The pore space of four different types of outcrop chalk: a) Stevns Klint, b) Kansas, c) flooded Liège, d) unflooded Liège. The segmentation of the flooded Liège sample shown here were performed by O. Plümper and Y. Liu at the Utrecht University (UU). The segmentation of the other samples were performed by H. Yoon at Sandia National Laboratories.

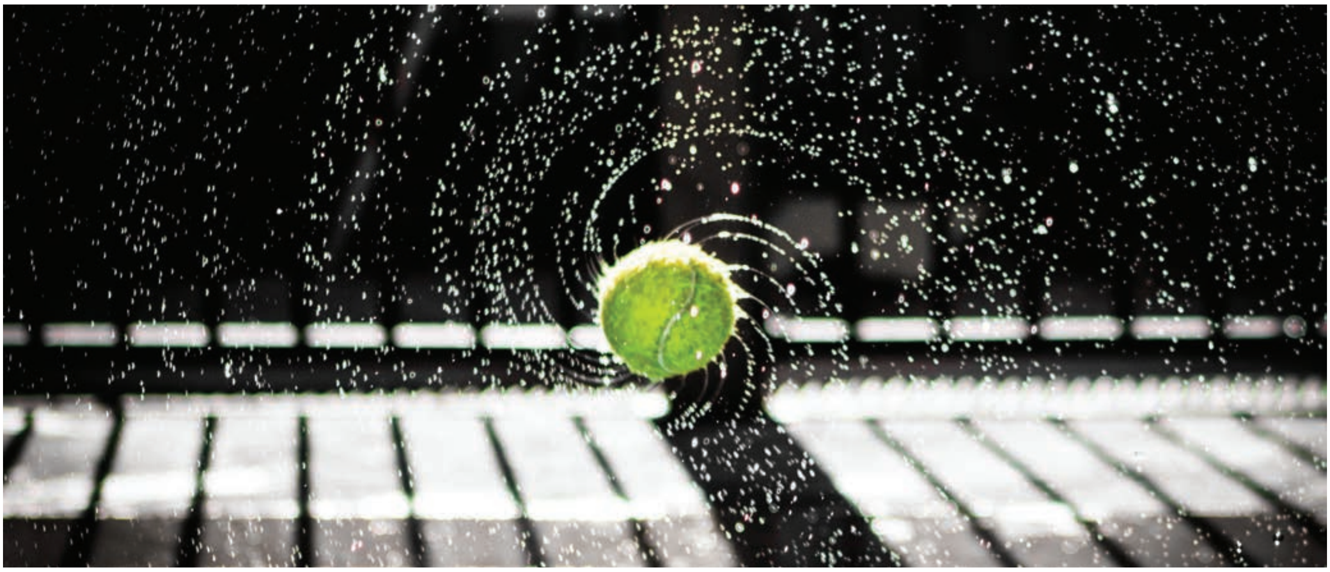
Figure 2 shows the final pore space geometry of four different chalk types: Stevns-Klint, Kansas, unaltered Liege, and Liege flooded with $MgCl_2$. These geometries will be an integral part of the numerical study of chemical flooding and two-phase flow in chalk. Using a lattice-Boltzmann model we have calculated the permeability, porosity and surface area of these samples, and the values are listed in Table 1. For the flooded Liege sample, we show the properties of two different segmentations of the same set of FIB-SEM images. Even though the original images are the same, the measured values are quite different. This illustrates the large uncertainty introduced during segmentation, which originate from the difficulty in defining a good criteria for separating the solid regions from the void regions. Quite often a manual treatment is necessary.

Chalk type	**Permeability [mD]**	**Porosity**	**Surface area [m2/g]**
Stevns Klint	0.93	0.32	0.96
Kansas	0.56	0.23	0.73
Liège, unflooded	0.22	0.27	0.83
Liège, flooded (UU)	2.6	0.50	1.2
Liège, flooded (SNL)	1.6	0.39	0.78

Table 1: Properties of the chalk samples shown in Figure 2 measured by lattice-Boltzmann simulations. The same FIB-SEM images of the flooded Liege sample were segmented by two different groups (Sandia National Laboratories and Utrecht University), and the properties of the final geometries are quite different. This illustrates the difficulty in obtaining a unique segmentation of the gray-scale FIB-SEM images.

SPIN-OFF PROJECTS

During 2016 The National IOR Centre of Norway expanded with several spin-off projects. Spin-off projects are a result of collaboration and activities within the Centre, but they are separated from the Centre and funded externally. It is a goal for the Centre to generate activity and attract additional funding. This shows the industry relevance of the research and results from the Centre and gives a good indication to how competitive the research partners are, both nationally and internationally. In 2016 the Centre partners succeeded in the national competition for funding from the Research Council in the Petromaks2 and DEMO2000. In addition to projects with public funding, several of the industry partners have commissioned contract research projects to test and implement results from the Centre in their organization.



PETROMAKS2 PROJECTS

Professor Morten Jakobsen from the University of Bergen is the project leader for the researcher project «Bayesian inversion of 4D seismic waveform data for quantitative integration of production data» awarded in December 2016 by the Research Council of Norway (RCN). The project is 100 % funded by the Research Council and is a direct result of the collaboration in the Centre between IRIS in Bergen and the University of Bergen. Geir Nævdal and Kjersti Solberg Eikrem from IRIS are involved in the project. Professor Morten Jakobsen has had a part time position in The National IOR Centre of Norway since the start in addition to his professor position at the University of Bergen.

Another interesting Petromaks2 project awarded in December 2016, is «Geosteering for improved oil recovery». The primary objective is to develop methodology for geosteering by continuously updating the earth model based on logging while drilling measurements including deep electro-magnetic measurements. The project has gained a lot of interest from our industry partners that covers both operators and a service company. This project is a result of collaboration between partners in The National IOR Centre of Norway and the SFI Centre DrillWell. The research partners are IRIS, University of Bergen and University of Stavanger.

INDUSTRIAL RESEARCH PROJECTS

Spin-off projects are a result of collaboration and activities within the Centre, but they are separated from the Centre and funded externally. Several of the Centre's user partners have commissioned spin-off projects to implement new methods and algorithms in their own preferred tool. Among these are one COREC project «Geomechanics and Permeability» funded by ConocoPhillips and the Ekofisk co-venturers, including TOTAL, ENI, Statoil and Petoro. This project is led by Professor Merete Vadla Madland at the University of Stavanger. Two other projects were funded by Statoil to improve the open source reservoir simulation tool OPM, «OPM performance 2016» and «OPM DenseAD 2016», both projects were led by Senior Scientists Robert Klöfkorn at IRIS. Another two other projects also funded by Statoil are «Alternative methodology for Robust Optimization – Gaussian Mixture (AGM)» (2015-2016) and «Robust Optimization for Reservoir Management» (2016). The two latter projects were led by Andreas Stordal, IRIS.

THE YOUNG AND INNOVATIVE

During 2016, the students have made great progress, and also been challenged to convey their research in new ways. Especially at IOR NORWAY 2016 almost all the PhD students in The National IOR Centre of Norway presented their posters, and participated in short stand-up sessions. This is only one of many ways in which the students have been trained in presentation techniques and been presented to the global IOR research environment.

All the students are expected to participate in conferences and symposiums relevant to their fields, and the results so far are very good. Close to all PhD students have participated in one or more conferences abroad during 2016.

There have also been several meetings within The National IOR Centre of Norway where the young researchers in particular have been emphasized. On November 8th all the PhD students and postdocs in The National IOR Centre of Norway were invited to a workshop. The main purpose of the workshop was to highlight the main ongoing R&D activities in the Centre, and to focus on the deliverables which are needed to achieve the listed milestones in the Centre's road map.

In 2016 all the PhD students located at University of Stavanger were given their own work and study room. By bringing all the students together, they will benefit from each other, and see how their projects interact with other fields of IOR research in the Centre.

The young researchers will continue to be one of the main priorities in the time to come, and in 2017 several dissemination and presentation seminars are planned for the PhD students. Here they will benefit from their own presentation coach, and be taught how to best present their research.

Photos: Elisabeth Tønnessen

The PhD students

Training and education of young researchers is an important activity in The National IOR Centre of Norway. Therefore, since the very beginning, emphasis has been placed on creating a creative and safe working environment for the PhD students and postdocs. in 2016 there were a total of 16 active PhD students, from 2017 this figure will increase to 18. There are currently 10 active postdocs in the Centre.

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

The project aims to increase knowledge of Raman spectroscopy applications for EOR processes and the understanding of mineral identification. Through the combination of micro- and nanoRAMAN and Atomic Force Microscopy (AFM), we will be able to identify the mineral phase and visualize the area.

The project will concentrate on the aspect of mineral growth, its predictability in chemical sedimentary rocks and the effects of flooding experiments on reservoir chalk, as well as possible clastic rocks.

Eystein Opsahl

Title: Investigating the environmental fate and effects EOR chemicals

The objective is to provide understanding about the behaviour of polymers used for EOR in the marine environment at low concentrations. This will be done by applying modern toxicological methods, well-established tests used in environmental risk assessment and state-of-the-art analytical techniques based on light scattering.

Aojie Hong

Title: Robust production optimization

This project investigates the economic aspect of robust optimization with and without additional information provided by history matching. The project provides a method to evaluate whether or not resources should be invested in order to obtain additional information before making a decision on production strategy.

Kun Guo

Title: Application of metallic nanoparticles for enhanced heavy oil recovery

The objective of this project is to perform a systematic study of the effect of metallic nanoparticles on enhanced heavy oil recovery, which covers the topics of the main cause of viscosity reduction, the parameters of nanoparticles and the thermophysical properties of nanoparticles containing fluids (nanofluids) on the recovery factor.

Shaghayegh Javadi

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

In spite of extensive research into the effect of fluid injection into chalk reservoirs, there are many questions still to be answered. Compaction, caused by fluid injection, has a strong impact on enhanced oil recovery and CO_2 sequestration. Variation in pore fluid chemistry causes some changes in the mechanical behaviour of chalk. This is believed to be caused by microscopic effects, which are not yet fully understood. The objective of this project is to study the adhesion force between two calcite grains in contact with a reactive fluid by developing a measurement method using Atomic Force Microscopy (AFM).

Remya Nair

Title: Smart Water for EOR by Membranes

The purpose of this project is to investigate the potential of using membrane technology to manufacture a specific chemical composition of the injected water. The smart water is usually made in the lab by adding salts to distilled water. Offshore the smart water has to be made using membrane technology from seawater or produced water. This is much more challenging and the process of making this as efficient (and costeffective) as possible is not currently understood.

Anna Kvashchuk

Title: Advanced Numerical Methods for Compositional Flow Applied to Field Scale Reservoir Models

This project addresses the forward simulation of IOR methods, and particularly investigates different numerical methods that can be applied to implement a compositional flow module for modeling the IOR/EOR. In the end, the project contributes to pilot simulations by providing a 'full field simulation tool' for water based IOR/EOR methods.

Mario Silva

Title: Development of water/oil partitioning tracers for determination of residual oil saturation in the inter-well region

This project intends to deliver tracers to measure residual oil saturation in flooded zones of the reservoir, which will also provide information about fluid circulation. This information will contribute to a more detailed characterization of the reservoir, identification of EOR targets and evaluation of EOR. operations. The main objective is to develop new oil/water partitioning tracers for partitioning interwell tracer tests (PITT) to measure remaining oil saturation in the flooded reservoir regions.

Tijana Voake

Title: Thermal properties of reservoir rocks, role of pore fluids, minerals and digenesis. A comparative study of sandstone, shale and chalk

The purpose of this project is to investigate how temperature gradients in the reservoir induced by the injection of cold water and cross flow may affect the mechanical strength of chalk. Different minerals have different expansion coefficients and this may lead to additional weakening. A better knowledge of the interplay between temperature effects and rock mechanical strength could lead to better drainage strategies.

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

This project will help to fully understand which processes govern alterations in texture, chemistry and mineralogy when flooding rocks with non-equilibrium brines. Furthermore, its contribution to completing the toolbox for studying IOR/EOR effects is very important. The project is also significant, if not paramount, in estimating compaction and porosity evolution in order to predict EOR-related topics.

Mohan Sharma

Title: CO_2 Foam EOR Field Pilots

This project aims to bridge this gap by conducting pilot studies in heterogeneous reservoirs of both clastics and carbonates. The project involves understanding the mechanisms on small and large scales for CO_2 Foam EOR. The overall project includes lab-scale studies, pilot-scale studies and the integration of data from various scales.

Irene Ringen

Title: Flow of non-Newtonian fluids in porous media

The purpose of this project is to design lab experiments that will provide information about the transport properties of polymer-based fluids in porous media. Polymer fluids are complex and there is currently no complete theoretical understanding of their transport properties in a reservoir where polymer molecules are exposed to temperature, salinity, and pressure gradients. This project will generate data and models that will be used in IORCoreSim and IORSim to predict the fate and effect of polymer flooding for improved oil recovery.

Jaspreet Singh Sachdeva

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

The purpose of this project is to investigate how the presence of oil in the pore space may affect the mechanical strength of chalk. Oil saturation varies in the reservoir due to the height above the oil-water contact and due to water injection. The presence of oil is therefore important, and the mechanical properties may be dynamic parameters that are constantly changing. A better knowledge of the interplay between rock-brine and rock-oil interactions could thus lead to better drainage strategies.

Samuel Erzuah

Title: Wettability estimation by oil adsorption

The purpose of this project is to ensure that the cores used for lab experiments have the correct initial conditions that are representative for the reservoir. The focus is to ensure that wettability conditions are prepared for SCAL and EOR experiments (e.g. smart water and polymer flooding) to generate representative inputs for the evaluation of EOR potential.

Yiteng Zhang

Title: Assemblage of different step size selection algorithms in reservoir production optimization

This project addresses the robustness and the efficiency of optimization algorithms, which essentially serve as a tool for evaluating different IOR pilots. The main objective of this project is to give a precise mathematical formulation of ensemble based optimization under geological uncertainty.

Oddbjørn M. Nødland

Title: Core scale modeling of EOR transport mechanisms

The purpose of this project is to improve the physical and numerical models in IORCoreSim. This is done by including models that take pore scale processes and geochemical interactions into account. The hope is that models take the underlying physical and chemical mechanism into account which are more robust when translated to a larger scale. The main objective of this project is to develop a numerical simulation tool and apply this to core scale data in order to gain a better understanding of various chemical processes occurring at a core scale.

THE ESTABLISHMENT OF THE SCIENTIFIC ADVISORY COMMITTEE REPRESENTS A HIGHLIGHT IN 2016. THE COMMITTEE WILL MAKE SURE THAT OUR RESEARCH IS OF THE HIGHEST QUALITY.

MERETE VADLA MADLAND, CENTRE DIRECTOR

HIGHLIGH

THE CENTRE PROVIDES UNIQUE OPPORTUNITIES TO DEVELOP SIMULATION TOOLS THAT WILL BE APPLIED TO REALISTIC FIELD CASES. THROUGH THE JOINT COLLABORATION BETWEEN THE RESEARCH PARTNERS AND INDUSTRY PARTNERS, I AM CONFIDENT THAT OUR SIMULATION TOOLS WILL LEAD TO A STEP CHANGE IN IOR OPERATIONS ON THE NORWEGIAN CONTINENTAL SHELF.

AKSEL HIORTH
RESEARCH DIRECTOR, THEME 1

I WILL HIGHLIGHT THE INTERNATIONAL RECOGNITION THE CENTRE HAS GAINED. IT IS GREAT THAT EAGE WANTS TO JOIN FORCES AND ARRANGE THEIR IOR SYMPOSIUM WITH OUR IOR NORWAY.

KRISTIN FLORNES
ASSISTANT CENTRE DIRECTOR

THE RESEARCH DRIVING FORCE FROM THE PHD STUDENT GROUP AND THEIR DISSEMINATION SKILLS IN PRESENTATION AND COMMUNICATION.

SVEIN SKJÆVELAND
DIRECTOR OF ACADEMIA

HTS 2016

I WOULD LIKE TO HIGHLIGHT THE INTEREST AND INCREASED COOPERATION WITH THE INDUSTRY PARTNERS. IT IS ENCOURAGING FOR ALL TO SEE THE DEVELOPED RESEARCH APPLIED ON REAL FIELDS.

RANDI VALESTRAND
RESEARCH DIRECTOR, THEME 2

THE INITIATIVE TO FACILITATE INTEGRATION OF RESULTS FROM THE ONGOING RESEARCH ACTIVITIES. THIS WILL SHOW THE TOTALITY OF THE WORK CARRIED OUT IN THE CENTRE.

SISSEL OPSAHL VIIG
DIRECTOR OF FIELD IMPLEMENTATION

DISSEMINATION AND MEDIA CONTRIBUTIONS

PHOTO: ALICE NIELSEN

DISSEMINATION

SELECTED HIGHLIGHTS 2016

It is vital that the research produced in The National IOR Centre of Norway is being disseminated at many different arenas. This is being done through conferences, seminars, symposiums and by publishing results in journals. However, there are many other ways to disseminate research. Some of the other arenas where The National IOR Centre of Norway has been present during 2016 is at ONS, OG21 and Forsker Grand Prix.

The researchers at The National IOR Centre of Norway really do travel all over the world, and they bring their results with them. In 2016 representatives from the Centre have been present at, among others, UK InterPore Joint Annual Meeting 2016, FORCE seminars, the Membrane Technology Conference 2016, IOR NORWAY 2016, SPE seminars, European Desalination Society events, the Goldschmidt 2016 Conference, CMWR in Toronto, The 11th International EnKF workshop, PDESoft in Warwick, ECMOR XV, ECOSS32, Society of Core Analysts' Annual Symposium, ICCGE-18 Nagoya, IEA-EOR Workshop & Symposium, GEOSTATS 2016, DEFI Gathering physico-chemical and flow properties, The DHRTC Technology Conference 2016, NFiP (Petroleum Research School of Norway) Stavanger and OG21 meeting 2016.

LUNCH & LEARN

In addition to all the dissemination done off-campus, the Lunch & Learn events have been very popular back on-campus at University of Stavanger. A total of 11 Lunch & Learn events have been held in the lunch room of the department of Petroleum Engineering at UiS. Most of the speakers have been researchers at The National IOR Centre of Norway, while some of them have been guests or collaborators of the Centre.

IOR NORWAY 2016

The most important event, and one of the main arenas for dissemination for The National IOR Centre of Norway is of course the IOR NORWAY conference. A total of 450 participants joined in on this two-day conference April 26-27 2016 and the two workshops before and after the main conference. The conference is still expanding, and in 2016 it also included poster sessions for PhD students, graciously sponsored by the Petroleum Research School of Norway.

ONS 2016

The National IOR Centre of Norway shared a joint stand with University of Stavanger, IRIS and DrillWell at ONS 2016. The stand included a video game developed especially for ONS, where the players aim to gather as much oil as possible from the reservoir, before time runs out. The game was a huge success, and can also be played at the PhD room at University of Stavanger. The ONS stand was also recognized by the jury awarding the prize for "Best Stand" at the exhibition. The stand was nominated in the category Best Stand, 50 square metres and smaller.

OG21

The game developed for ONS was also part of the stand The National IOR Centre of Norway had at OG21 in November 2016. The stand was manned by PhD students and members of The Management Team. The National IOR Centre of Norway was also represented with presentations by Assistant Director Kristin Flornes and PhD student Anna Kvashchuk. Flornes presented on the topic of how OG21 influence research strategies, while Kvashchuk was one of a few selected students chosen to highlight solutions for future technology needs.

FORSKER GRAND PRIX

Another PhD student worth an honourable mention is Jaspreet Singh Sachdeva, whom performed at Forsker Grand Prix in Stavanger. Sachdeva presented his work on "How to trick the most oil from a stone?" and spent his presentations giving a brief introduction to IOR, more specifically waterflooding of chalk, and how compaction can have fatal consequences out in the fields. While he did advance to the second part of the competition, he was unfortunately not among the top two to advance to the national finale, as he landed on third place.


17 Johan Sverdrup-er ligger og venter
300 eksperter samlet i Stavanger. I potten ligger 30 milliarder fat olje og gass.
Risiko og skatt i petroleumssektoren
Finansdepartementets feilregning gir ny debatt om kutt i risikoen og hopp i oljeinntektene for staten. Bare det var så enkelt.
Mastering EOR challe
JAKTEN PÅ DE VERDIFULLE OLJERESTENE
Irene Ringen første vinner av Skjævelandprisen!
IOR NORWAY 2017 in collaboration with EAGE 24-27 April 2017
Registration is now open
NEWS FROM THE NATIONAL IOR CENTRE OF NORWAY:
IOR NORWAY 2017 in collaboration with EAGE - The 19th European Symposium on Improved Oil Recovery
IOR NORWAY 2017 / The 19th European Symposium on Improved Oil Recovery will be held from 24-27 April 2017 in Stavanger, Norway. This will be jointly hosted by EAGE and The National IOR Centre of Norway, combining the top two European IOR conferences into one meeting.
The Energy Year 2017: Oil - an industry in change
The oil industry is changing, for better and for worse. This was the topic for the meeting arranged by Næringsforeningen on February 1st. Centre Director Merete Vadla Madland was one of the members of the resource group arranging the meeting.
Learning to communicate from the stage
On January 26th all PhD students and postdocs in The Centre were invited to participate in the first of several workshops on the topic of dissemination and communication from the stage.
Seniorforskar Siv Marie Åsen og forskingsdirektør ved det nasjonale IOR-senteret Aksel Hiorth (Foto: Mari Løvås)
- Dette er ei utfordring i høve til teknologien og utstyret som trengs for å auka utvinninga frå felta gjennom bruk av IOR (Improved oil recovery), og forsking er nøkkelen til at dette skal lukkast, seier Aksel Hiorth, professor ved Det teknisk-naturvitenskapelige fakultet ved Universitetet i Stavanger.
Hiorth er forskingsdirektør ved det nasjonale IOR-senteret og har dermed ansvar både for arbeidet med oppskalering og forbetring av nye utvinningsmetodar og for at fotavtrykket frå IOR-arbeidet skal bli så lite som råd er.
Nasjonal dugnad
Senteret er i hovudsak finansiert av Forskningsrådet og er gitt oppdraget med å utvikla

JOINING FORCES: VISITING THE USER AND RESEARCH PARTNERS

Joining forces to recover more – collaboration is one of the key elements to success in The National IOR Centre of Norway. The user partners from the industry provide a valuable entrance to important data and expertise needed in order to succeed.

With this as background, the management team of The National IOR Centre of Norway decided to begin their user partner tour in 2016, and visited several of the partners and collaborators in the Centre.

«This will take time, and we plan to continue this tour in the time to come, but we are happy that the ball is rolling - and for the amazing hospitality the visited partners have shown us,» says Centre Director Merete Vadla Madland.

She hopes these visits will strengthen the bond between academia and the industry:

«We rely on each other in order to achieve our goals, so this is one of many ways to improve our relationship with the industry,» Madland says.
«The industry and our user partners have a unique knowledge and wisdom that we rely on when we perform our studies in the Centre,» she says.

During 2016 the management team visited BP, Maersk, Statoil's research centre in Trondheim and ENI R&D centre in Milan. The plan for 2017 is partly set, and Madland hopes to visit as many as possible of the user partners.

«With busy schedules it is not always easy to plan trips with several members of the management team, but we hope to visit several other partners in the time to come,» she says.

«Experience has shown that by moving away from our offices and computers and actually meeting our partners we build much better and more open relationships, and we learn much more than we otherwise would have,» she says.

Madland highlights that her door is always open if representatives from the industry wish to visit the facilities at University of Stavanger:

«We have had many visitors from all over the world, and we are always happy to welcome guests to a tour of our facilities,» she says.

The visits performed by representatives of The National IOR Centre of Norway are not limited to the user partners, but also involves collaborators and other interested parties. Examples of other visits from 2016 include trips to DTU and GEUS in Denmark and Imperial College in London.

Photo: Representatives from The National IOR Centre of Norway visiting ENI in Milan. From left: Tor Bjørnstad (IFE), Kristin Flornes (IRIS), Jan Ludvig Vinningland (IRIS), Randi Valestrand (IRIS), Merete Vadla Madland (UiS), Geir Nævdal (IRIS), Bente Dale (UiS) and Aksel Hiorth (UiS/IRIS). (Photo: Private)

"WE HAVE HAD MANY VISITORS FROM ALL OVER THE WORLD, AND WE ARE ALWAYS HAPPY TO WELCOME GUESTS TO A TOUR OF OUR FACILITIES."

CENTRE DIRECTOR, MERETE VADLA MADLAND

Photo: Aksel Hiorth of The National IOR Centre of Norway visiting Imperial College in London. (Photo: Private)

IOR NORWAY 2016

RECOVER FOR THE FUTURE

The second conference hosted by The National IOR Centre of Norway in collaboration with the Petroleum Research School of Norway was held April 26-27, with related workshops on April 25 and 28. Despite the bad times in the oil industry, close to 450 participants joined the conference and workshops.

«I am very happy to see the enthusiasm and optimism many of the speakers are showing. In The National IOR Centre of Norway we are entusiastic about the future – Improved recovery is an area ripe for further research and development, especially as pressures now grows for more efficient, cost reducing and enironmentally sensitive operations,» says Centre Director, professor Merete Vadla Madland.

«The oil price will once again increase and then, more important than ever, it will be crucial to have the unique competence as we together push and work forward in The National IOR Centre of Norway. We will recover,» she says.

SECOND CONFERENCE

This is the second conference arranged by The National IOR Centre of Norway, last year more than 300 people signed up for IOR NORWAY 2015.

«We are very close to the same number of people this year, and for me this is a great honor,» Madland says. «This means that what we do is important, and it inspires us to work even harder.»

GETTING INTERNATIONAL RECOGNITION

«It is indeed inspiring for us in The National IOR Centre of Norway to see that the conference, and the research we do, have an international impact,» says Madland.

During the conference she has had the pleasure of meeting many interesting people, that might collaborate in The National IOR Centre of Norway in the future.

POSTER SESSIONS WITH NFIP

New at IOR NORWAY 2016 were PhD poster sessions. In collaboration with the Petroleum Research School of Norway (NFiP), The National IOR Centre of Norway invited PhD candidates from Norwegian universities to the IOR NORWAY 2016 POSTER SESSION.

A total of 24 PhD candidates had sent in their posters, and presented at one-minute stand-up sessions. The most promising candidate was awarded the Skjæveland Award, a newly established prize, awarded to promote great research and promise. After two long days of evaluating, the winner was elected: Irene Ringen from The National IOR Centre of Norway.

NEXT YEAR

«We are very happy to announce that next year's conference will be hosted in collaboration with EAGE under the theme: Sustainable IOR in a Low Oil Price World,» says Madland.

The next conference will be held 24-27 April 2017.

All photos by Mari Løvås/The National IOR Centre of Norway

Photo: Judging the PhD posters: The Committee had a tough decision to make, when they had to decide who would win the first ever Skjæveland Award.

Photo: The debate - speakers Margot Gerritsen, Randy Seright and Arne Stavland at IOR NORWAY 2016.

Photo: Karl Eirik Schøtt-Pedersen, Director General at Norsk olje&gass, presenting the topic "Making the impossible, possible. What's needed to take oil recovery on the NCS to the next level?"

Photo: Close to 300 participants, among them Dean of the Faculty of Science and Technology, Øystein Lund Bø, made the conference a success.

Photo: PhD student Irene Ringen from The National IOR Centre of Norway won the first ever Skjæveland Award. The award was presented by Rector Marit Boyesen.

Top left: After each session, speakers were invited to a panel debate. Margot Gerritsen, Randall Seright and Arne Graue during one of the debates.
Top right: Siri Helle Friedemann and Ingrid Anne Munz from the Research Council of Norway.
Middle: Effort has been put into making IOR NORWAY a conference not only for high quality presentations, but also for networking and meeting researchers and other interested parties from all over the world.
Bottom left: Karl Eirik Schøtt-Pedersen, Director General at Norsk olje&gass discussing the future of oil and gas with Centre Director Merete Vadla Madland and Assistant Centre Director Kristin Flornes.
Bottom right: The PhD students participating in the poster sessions had their posters on display outside the conference hall. PhD Tijana Voake explains her research to Ida Lykke Fabricius.

«IT IS SO INSPIRING FOR US IN THE NATIONAL IOR CENTRE OF NORWAY TO SEE THAT THE CONFERENCE, AND THE RESEARCH WE DO, HAVE AN INTERNATIONAL IMPACT.»

MERETE VADLA MADLAND, CENTRE DIRECTOR

Photo: Professor Svein Magne Skjæveland - the man who inspired the Skjæveland Award. Here pictured with the winner of the 2016 award, Irene Ringen.

Photo: All participants were encouraged to make new connections during the conference. Here Professor Arne Graue with Centre Director Merete Vadla Madland.

Photo: Professor Mary Wheeler, The University of Texas at Austin. Prof. Wheeler is a world-renowned expert in computational science, and presented «Methodologies and robust algorithms for subsurface simulators» at IOR NORWAY 2016.

THE SKJÆVELAND AWARD

In honor of Svein Magne Skjæveland's extensive contribution to the establishment of the petroleum education programmes and his work for The University of Stavanger, the first Skjæveland Award was presented at IOR NORWAY 2016. The award is given to a young researcher who shows excellence, courage and innovation in his/her research, and should motivate for further bold moves towards optimizing oil and gas production.

A total of 24 PhD students presented their posters at IOR NORWAY 2016, and the quality of their work was very high. In the end, one winner stood out: Irene Ringen from The National IOR Centre of Norway. Ringen presented her poster on «Resistivity measurements and polymer flooding of sandpacks with dual-porosity.»

«Wow! I did not expect to win at all,» says a very moved award-winner. «I did not even prepare a thank-you speech!» she exclaims and laughs. Despite not being prepared, Ringen thanked her supervisors Arne Stavland (IRIS) and Aksel Hiorth (UiS/IRIS) for all their help.

The evaluation committee consisted of:
Mariann Dalland, NPD
Eirik Jenssen, Dong Energy
Martin Fernø, University of Bergen
Espen Jettestuen, IRIS

STATEMENT FROM THE COMMITTEE:
Ringen's work is well aligned with the conference theme, and future opportunities on the Norwegian Continental Shelf. Her PhD stand-up presentation was excellent, and the committee is impressed with her level of clarity and her understanding of the research.

THE SKJÆVELAND AWARD
The award background, as presented by Rector Marit Boyesen, 27 April 2016:

IOR is today a household word in academia and a default tool for the oil and gas business for planning, developing and operating oil and gas fields – be it offshore on onshore.

This has not always been the case. Neither has IOR emerged as a modus operandi solely by its own virtue. On the contrary, our present day IOR regime is the result of hard work by dedicated professionals and specialists within the art of going the extra mile for more barrels.

Strategic industry efforts have been the key driving force when it comes to producing «more hydrocarbons for the buck», while at the same time reducing the environmental footprint. This is today the standard IOR operating model – with governments as well as with the industry.

Nothing of this has emerged by itself. It has been built stone by stone by dedicated scientist and engineers, projects and operating organisations, governments and academia in a common understanding that we should jointly do our utmost to make the reservoirs yield whatever is possible.

The prize that is being awarded today is in recognition of these efforts and should motivate for further bold moves towards optimizing oil and gas production. It is also an award to highlight the young researchers, as they are the future of improved oil recovery on The Norwegian Continental Shelf. I would like to add that we are very honored that The Petroleum Research School of Norway, NFiP, has sponsored all the PhDs presenting posters this year.

A key element in improving the oil recovery is to understand the fundamental processes that control the flow of fluids in a porous rock at pore-, core-, and field scale. One academician who has played a particular role in this regard is Director of Academia at The National IOR Centre of Norway, Professor Svein Magne Skjæveland. Not only through his academic research, but also as a key player in establishing long term research programmes, such as RUTH, SPOR, COREC and The National IOR Centre of Norway.

Photo: The happy winner, Irene Ringen from The National IOR Centre of Norway (Photo: Mari Løvås/The National IOR Centre of Norway)

He has himself received a number of awards and recognitions for his research, his teaching and for his contribution to the oil and gas profession as a specialist and as an editor of several technical publications. Skjæveland has been a cornerstone in the transition to a university. He was one of the strongest voices in the establishment of the petroleum programmes at the university, and later the first doctoral programmes at University of Stavanger in petroleum technology and offshore technology.

In 2009 Skjæveland received the SPE North Sea Region Formation Evaluation Award and he has also been a board member and European Director for Society of Core Analysis.

Svein Magne is presently Professor Emeritus with the Institute for Petroleum Technology at the Faculty of Science and Technology at the University of Stavanger and Director of Academia at The National IOR Centre of Norway.

The University of Stavanger together with The National IOR Centre of Norway has decided to honour Professor Svein Magne Skjæveland's extensive contribution to the field of petroleum science by announcing that as of today the official name of this prestigious award will be «Svein Skjæveland Award».

AWARDS AND NOMINATIONS

Photo: Master student Håkon Sunde Bakka was awarded the Best Master Student Award 2016 by SPE Stavanger (Photo: Mari Løvås/ The National IOR Centre of Norway)

Photo: Postdoc Bergit Brattekås won the award for best presentation at SPE Bergen one-day seminar in April. (Photo: Private)

- PhD student Irene Ringen won the first ever Skjæveland Award for her poster and presentation at IOR NORWAY 2016, 26-27 April.
- Master student Håkon Sunde Bakka was awarded the Best Master Student Award 2016 by SPE Stavanger for his excellent academic performance at University of Stavanger.
- Postdoc Bergit Brattekås won the award for best presentation at SPE Bergen one-day seminar in April.
- The joint stand between The National IOR Centre of Norway, University of Stavanger, DrillWell and IRIS was nominated for Best Stand at ONS 2016.
- PhD student Jaspreet Singh Sachdeva came in third place at Stavanger Forsker Grand Prix.

Photo: We were nominated for Best Stand at ONS 2016. (Photo: Mari Løvås/ The National IOR Centre of Norway)

Photo: PhD student Jaspreet Singh Sachdeva came in third place at Stavanger Forsker Grand Prix. (Photo: Asbjørn Jensen/University of Stavanger)

COLLABORATION AND MOBILIZATION

DANISH PROFESSOR THRIVES AT THE NATIONAL IOR CENTRE OF NORWAY

Photo: «Chalk and Chinese» was the theme when chalk specialist Ida invited colleagues at University of Stavanger to lecture at lunch (Photo: Mari Løvås/The National IOR Centre of Norway)

«Research is by nature a slow process and continuity is a requirement for good results,» emphasizes Professor Ida Lykke Fabricius. The experienced Danish geologist can be found at the University of Stavanger, where she has a twenty percent position as professor II financed by COREC. She is also actively involved in the research carried out by The National IOR Centre of Norway at the University of Stavanger.

Fabricius has her doctorate in technical geology from the Technical University of Denmark (DTU) in Copenhagen. There she practices teaching and research within technical geology, with an emphasis on understanding and describing the geological layer's physical properties. It should not surprise anyone that a geology professor from Denmark, which is virtually without visible bedrock, is a specialist in chalks. Chalk can be found more or less across the country - in some places in thick layers of almost a thousand meters.

LONG LASTING RELATIONS TO STAVANGER

«This was also the reason for my first contact with the geological environment at University of Stavanger, which goes back to an exciting collaboration with Professor Rasmus Risnes and his colleagues in the early 90s. Subsidence of the seabed in and around the producing fields in the North Sea generated a huge research work which was intended to understand why the chalks collapsed when the reservoir pressure was reduced due to production,» says Fabricius.

She highlights an exciting collaboration with several of the key personnel at The National IOR Centre of Norway, and research around this. In addition, three years working in Maersk has given her useful experience from oil and gas operations and of management in general.

EDUCATIVE COOPERATION

«I like it here in the Centre, and working with current issues related to improved recovery and the chalks' role in this, though it is also part of my role to «poke the axioms»,» says Fabricius, without acting like a watchdog from the continent. On the contrary, she emphasizes that there are a lot of good learning in working closely with the IOR environment at Ullandhaug.

«It is a bit of a plus that I do not have to do administrative work while I am in Stavanger,» she smiles in her modest Danish way.«I can therefore focus completely on learning and collaboration while I am in here, and take advantage of what the others are working on, and collaborate on finding solutions to complicated questions. This takes time. Continuity of scientific work is extremely important, in the same way as experience is,» she clarifies. Fabricius thinks she all too often witness the value of the quality of data being undervalued in the research.

Text: Lars Gunnar Dahle, UiS

COLLABORATION

An open structure is important for The National IOR Centre of Norway. Cooperation and openness are key words 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.

COLLABORATION: UNIVERSITY OF BERGEN:
KEY CONTACTS: Professor Arne Graue, Associate Professor Martin Fernø at the Department of Physics and Technology, Professor Morten Jakobsen at the Department of Earth Science, University of Bergen.
PHD / POSTDOC: 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. Brattekås, who also previously has worked for the Centre, is now financed through a postdoc position at The National IOR Centre of Norway.

Professor Morten Jakobsen fills a 20 % position at IRIS under The National IOR Centre of Norway as a way to increase the Centre's expertise in geophysics. This is especially important for activities that involve the use of 4D seismic data in reservoir characterization and assisted history matching (data assimilation). The IRIS research group working with 4D data has weekly meetings with Professor Jakobsen, where research results and research initiatives are discussed and key references are given. This work has resulted in several joint articles in 2016: A Journal article published in Computational Geosciences: 1) «Bayesian estimation of reservoir properties-effects of uncertainty quantification of 4D seismic data», and further work is in progress within uncertainty quantification. 2) A conference article was presented at the SPE Bergen One-Day seminar, «An Ensemble 4D Seismic History Matching Framework with Sparse Representation Based on Wavelet Multi Resolution Analysis» in April, 3) The latter has now been revised and published in SPEJ.

UNIVERSITY OF OSLO:
KEY CONTACTS: Professor Dag Dysthe, Dr. Anja Røyne, Professor Anders Malthe-Sørenssen, MSc Sigve Skattum
PHD: 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 cooperation

SINTEF:
KEY CONTACTS: Dr. Knut-Andreas Lie, Dr. Atgeirr Flø Rasmussen, Dr. Xavier Raynaud

IRIS and SINTEF collaborate to develop the open reservoir simulator OPM. Further work is now in testing and research is being done on numerical methods that can be implemented in this simulator. Especially the work of one of the Centre postdocs at IRIS performed in relation with Sintef on higher-order methods to improve the simulation of polymer flooding. A conference article "Fully Implicit Higher-order Schemes Applied two Polymer Flooding" on this work was published this year at ECMORVX, this is now under consideration for publication in the Journal of the Conference. The next publication of this work is being developed.

DTU / GEO / GEUS:
KEY CONTACTS: Professor Ida Lykke Fabricius, Chief Engineer Helle Foged Christensen and Dr. Claus Kjøller
PHD: Tijana Voake
Professor Fabricius is also employed as Professor II at the University of Stavanger and is supervisor for one of the PhD students in The National IOR Centre of Norway, as well as several MSc students.

TNO:
KEY CONTACTS: Olwijn Leeuwenburgh, Philippe Steeghs, Rahul Fonseca
POSTDOC: Yanhui Zhang
TNO has a 2-year postdoc research project as official contribution to The National IOR Centre of Norway and which project ceases in spring 2017. The postdoc's research deals with the application of data assimilation using 4D seismic data to a field case. The research will be supervised by researchers at TNO, such as Olwijn Leeuwenburgh and Philippe Steeghs. The 4D data-researchers at IRIS have meetings with the TNO postdoc and supervisors biweekly. The National IOR Centre of Norway also collaborates with TNO in production optimization, and in particular with Dr. Rahul Fonseca in the development of improved algorithms. This does not concern an official contribution of TNO to The National IOR Centre of Norway, but is an exchange in this field with IRIS valuable for both parties.

History matching using data assimilation, the use of 4D data and production optimization are key research areas of The National IOR Centre of Norway, where IRIS are especially specialized, and where TNO has complementary expertise. The partnership will strengthen the research and aids in making the Centre one of the international leader in these fields. Through this relationship the Centre also gains knowledge of customers, typically operators on the Norwegian Continental Shelf (NCS). This in turn provides an increased knowledge about research needs and challenges on the NCS.

TU DELFT:
<u>KEY CONTACTS:</u> Professor Jan Dirk Jansen (TU Delft), Rafael Moraes (TU Delft / Petrobras)
Professor Jan Dirk Jansen is the head of department of Geoscience & Engineering and professor of Reservoir Systems and Control at the University TU Delft. IRIS is engaged in a research collaboration with TU Delft in production optimization, and senior researcher Andreas Stordal is annually invited by Professor Jan Dirk Jansen to stay at TU Delft as a guest professor. In 2016 Stordal stayed there for 9 weeks. The collaboration will strengthen the research and make the Centre stand out internationally in the field.

CORNELL UNIVERSITY:
<u>KEY CONTACTS:</u> Professor Lawrence M. Cathles III
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 define the limit of detection for these tracers, in addition to implement dynamic experiments to look at the particles' flooding properties.

UT AUSTIN:
<u>KEY CONTACTS:</u> Professor Larry Lake
Project Collaboration: Robust Production Optimization. Included in this collaboration is the use of less detailed models (CRM - Capacitance Resistance Model) for reservoir simulation for use in optimization. One of the PhD students and a professor in The National IOR Centre of Norway are involved in this, and both are planning to spend a semester at UT in 2016/17.

INSTITUTE FOR THE STUDY OF THE EARTH'S INTERIOR (ISEI):
<u>KEY CONTACTS:</u> Professor Eizo Nakamura
Project: Quantification of chemical changes in flooded chalk on homogenized and natural
samples with FE-TEM.
Research Assistant: MSc. Nina Egeland, has been on a research stay in Japan during the period January-June 2016.

TU BERGAKADEMIE FREIBERG, INSTITUTE FÜR MINERALOGIE, GERMANY
<u>KEY CONTACTS:</u> Bernhard Schulz and Jens Gutzmer
TU Bergakademie Freiberg is one of Task 2's main partners and several students have been here for analyzing rock samples. Freiberg is a traditional mining town in Germany, and has a strong focus on geology and mineralogy. the Centre has worked with them in areas such as MLA (Mineral Liberation Analyzer) and Microprobe to study chemical, mineralogical and textural changes as a result of EOR methods.

ECOLE POLYTECHNIQUE PARIS, FRANCE
<u>KEY CONTACTS:</u> Razvigor Ossikovski and Chiara Toccafondi
At this collaborating laboratory in Paris, the Centre researchers use nanoRaman to identify the mineralogy of the surface of thin section samples. Here the researchers are working to be able to see the smallest minerals formed when flooding chalk cores with EOR water to produce more oil. With this method we are able to study minerals on the nanometre scale of less than 50 nm.

UNIVERSITÉ DE LYON:
<u>KEY CONTACTS:</u> Olivier Tillement
IFE cooperates with Olivier Tillement at Université de Lyon. The cooperation involves characterisation of various 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):
<u>KEY CONTACTS:</u> Senior researchers Dorit Hammerling and Ram Nair
Robert Klöfkorn was in 2015/2016 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 consists of specialists in mathematical and statistical methods to simulate and predict complex stochastic phenomena.

UNIVERSITY OF STUTTGART:
<u>KEY CONTACTS:</u> Birane Kane
PhD student Birane Kane visited IRIS for 3 months during spring 2016. Kane is working on development of discontinuous Galerkin methods for flow in porous media with Robert Klöfkorn and other researchers on simulator development at IRIS-Bergen. Dr. Klöfkorn also taught «DUNE/FEM» summer school at the University 26 to 30 September 2016.

UNIVERSITY OF WARWICK:
<u>KEY CONTACTS:</u> Professor Andreas Dedner
Professor Andreas Dedner works with numerical analysis, and is a partner in the development of DUNE framework OPM relies on. Dr. Robert Klöfkorn is the collaborator from The National IOR Centre of Norway.

The National IOR Centre of Norway believes in transparency, and that through cooperation the best results will be found. Therefore, it is vital to form a good network to use in the research produced. This network spans around the world, and helps to ensure the quality of the research, while it also aids in making The National IOR Centre of Norway stand out as when it comes to IOR research worldwide.

Photo: Collaboration is the main foundation of The National IOR Centre of Norway. The three research partners University of Stavanger, IRIS and IFE are collaborating, both with each other, but also with a number of national and international partners. Siv Marie Åsen (IRIS) and Aksel Hiorth (UiS/IRIS) are some of the researchers working together to find ways to improve the oil recovery on the Norwegian Continental Shelf. (Photo: Mari Løvås/The National IOR Centre of Norway)

JOINING FORCES TO RECOVER MORE

Photo: Ole Ringdal (to the left) and Kristin Flornes from IRIS visiting friends and collaborators in Denmark. Here with Bo Cerup-Simonsen, of The Danish Hydrocarbon Research and Technology Centre. (Photo: Private)

Photo: Professor Lawrence M Cathles, III, from Cornell University has been collaborating with researchers in The National IOR Centre of Norway for a long time. He was invited to sum up the IOR NORWAY 2016 conference. (Photo: Mari Løvås/The National IOR Centre of Norway)

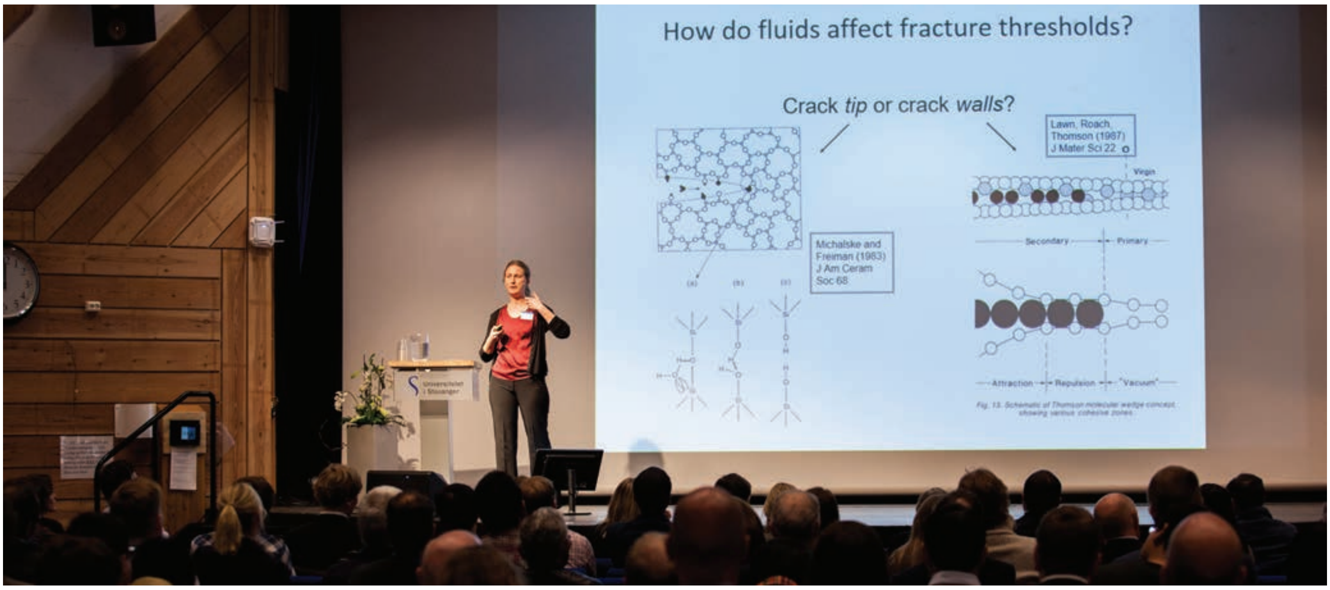


Photo: Anja Røyne from University of Oslo presenting at IOR NORWAY 2016. (Photo: Mari Løvås/The National IOR Centre of Norway)

Photo: One of the Centre collaborators from University of Bergen, Arne Graue, presenting at IOR NORWAY 2016. (Photo: Mari Løvås/The National IOR Centre of Norway)

THE MOST IMPORTANT THING WE CAN DO IS TO COLLABORATE. WE NEED INPUT, NOT ONLY FROM ACADEMIA, BUT FROM THE INDUSTRY AND RESEARCH INSTITUTIONS WITH EXPERIENCE AND KNOWLEDGE. BY JOINING FORCES WE CAN RECOVER MORE, AND BENEFIT FROM EACH OTHER.

MERETE VADLA MADLAND,
CENTRE DIRECTOR

Photo: The University of Stavanger has a long lasting relationship with Lesley James and Memorial University of Newfoundland. Dr. James has visited The National IOR Centre on many occasions, and participated at IOR NORWAY in 2016 and 2015, as well the opening in 2014. Photo: Mari Løvås/The National IOR Centre of Norway

Photo: The collaboration with TU Delft and TNO in the Netherlands is especially important to the researchers in theme 2 in the Centre. Professor Jan Dirk Jansen from TU Delft presented the topic «Optimization of subsurface flow» at IOR NORWAY 2016 (Photo: Øyvind Torjusen/SCREEN STORY)

Photo: «By joining forces we will be able to recover more.» That is the message from Aksel Hiorth, leader of Task 1. In his work with the development of the IORSim he is working with researchers from several different research institutions as well as from the industry. «By using unique knowledge and experiences, we will be able to make the best simulator for predicting the impact of IOR processes on the field scale,» he says.

INTERNATIONAL COLLABORATOR:TNO

TNO is the Netherlands Organisation for Applied Scientific Research. It has as its mission to connect people and knowledge to create innovations that boost the sustainable competitive strength of industry and well-being of society. TNO is active on the social themes Industry, Healthy Living, Defence, Safety & Security, Urbanisation and Energy, and employs more than 2500 staff members spreaded over several locations in The Netherlands, as well as three foreign offices (Qatar, Aruba and Singapore).

The TNO Geo Energy department in Utrecht, which hosts all applied geoscientific research activities, cooperates as foreign partner in The National IOR Centre of Norway on a 2-year project with as main objective development and application to a field case of ensemble based data assimilation techniques for history matching to 4D seismic data. To this 2-year project that will finish in May 2017 a post-doc has been assigned who works together with senior TNO research staff.

To achieve this main objective, TNO has been focused on investigating and improving their developed approach on seismic history matching at field scale. This new approach facilitates the incorporation of time-lapse seismic data into history matching workflows through a combination of ensemble-based data-assimilation methods and a distance parameterization of flood fronts derived from time-lapse seismic anomalies. The potential advantages include a significant reduction in the number of data points and flexibility in the type of attributes from which the front information can be extracted.

After taking the Norne field as our working field case based on its multiple high-quality seismic surveys and public access, the research is carried out in two directions. On the one hand, efforts were made to improve the applicability of the TNO workflow in real-field history-matching cases by extending it to be able to deal with reservoir models defined on generic corner-point grids and to be more robust to the models with complex saturation-front patterns. These improvements were verified by a series of numerical experiments on synthetic realistically complex test cases. The research results have been presented at international conferences and then submitted to related academic journals. On the other hand, observations of front positions were acquired via an inversion of the Norne AVO seismic data set. These achievements mainly based on geophysical expertise are going to be presented at the conference of IOR NORWAY 2017. In a last step TNO will do a final demonstration of the improved methodology with the obtained real field data.

During our project activities there are frequent meetings between the TNO team, the task 7 leader and a research team at IRIS that is also working on 4D data. The cooperation has given us the opportunity to discuss and develop new ideas and improve the applicability of our methodology to field cases. Benefits for The National IOR Centre of Norway are that the results are shared with all other Centre partners. Furthermore, any near-future application of the developed workflows to field cases will be of direct benefit to the operator and other partners of the assets because of the expected improvements in the quality of the reservoir models, as quantified by the match to historic data, the uncertainty in model parameters, and the robustness of model forecasts.

The National IOR Centre of Norway has an open structure which is something that TNO highly values. As the Centre is organized around 11 user partners, three Norwegian research partners and around cooperation with many more Norwegian and foreign research institutes, it gives TNO access to a relative large community cooperating in several disciplines in which the Geo Energy department of TNO is active. We think the organization of The National IOR Centre of Norway is highly professional and we recognize that research is being performed on a high scientific level.

NATIONAL COLLABORATOR: PROFESSOR MORTEN JAKOBSEN

Professor Morten Jakobsen at the Department of Earth Science of the University of Bergen has a 20 percent position at IRIS under The National IOR Centre of Norway to strengthen the Centre's competence within mathematically oriented petroleum geophysics. Professor Jakobsen has a strong track record in rock physics, seismic waveform inversion and integrated petroleum research. He also has a degree in physics that make him very flexible when it comes to initiation of interdisciplinary projects.

The collaboration with Jakobsen is especially important for activities that deal with the use of 4D seismic data in reservoir characterization and seismic history matching. In collaboration with the Chief Scientist Geir Nævdal and Researcher Kjersti Eikrem, Professor Jakobsen have recently obtained funding from the Petromaks2 program of the Research Council of Norway for a researcher project called «Bayesian inversion of 4D seismic waveform data for quantitative integration with production data». This project represents a direct spinoff project from The National IOR Centre of Norway, and indicates the direction that the research efforts of this 4D seismic team will move in the next couple of years.

The main idea behind the new Petromaks2 project is that a combination of a scattering integral approach to full waveform modelling with state-of-the art Bayesian inversion methods can be used to obtain information about the uncertainty as well as the most likely values of the elastic parameters in a reservoir under production. It is generally accepted in industry that better estimates of uncertainties is crucial for a successful quantitative integration of 4D seismic and production data, which in turn, can help us to maximize oil and gas production from the Norwegian Continental Shelf.

The new Petromaks2 project will provide funding for a new PhD student as well as funding for research performed by Geir Nævdal and Kjersti Eikrem at IRIS. The new PhD student will get the opportunity to collaborate with some of our international partners within seismic modelling and imaging at the Czech Academy of Sciences and the University of California, Santa Cruz.

Several M.Sc. projects at the Department of Earth Science of the University of Bergen will also be linked with the new Petromaks2 project.

The fact that Jakobsen and his collaborators at IRIS are focusing on the development of methods for full seismic waveform inversion, rather than conventional seismic amplitude versus offset analysis, means that there is a potential for groundbreaking fundamental research as well as more applied research. Efforts to make more efficient use of rock physics models within the contexts of full waveform inversion and seismic history matching represents a unique feature of this collaboration between the 4D seismic group at IRIS and the Department of Earth Science of the University of Bergen.

Jakobsen is currently a member of the scientific committee for the 4th International Workshop on Rock Physics, and have also been a chairman for a SEG session on full waveform inversion, so The National IOR Centre of Norway are in a very good position to explore the development of such modern geophysical methods. As indicated above, the collaboration between The Centre and Professor Morten Jakobsen is very stimulating for both partners.

The main feedback from Jakobsen is that his collaboration with The National IOR Centre of Norway has helped him to identify research topics of particular strong interest in industry. At the Centre,we benefit from having contact with academic researchers in geophysics, since our expertise has traditionally been focused towards fluid flow in porous media rather than seismic methods.

NATIONAL COLLABORATOR: THE DEPARTMENT OF PHYSICS AND TECHNOLOGY AT UNIVERSITY OF BERGEN, WITH PROFESSOR ARNE GRAUE

The collaborative research efforts between The National IOR Centre of Norway and the Reservoir Physics group at the Department of Physics and Technology at University of Bergen, emphasized in 2016 two main projects:

INTEGRATED EOR FOR HETEROGENEOUS RESERVOIRS

The National IOR Centre of Norway and the Reservoir Physics Group at the Dept. of Physics and Technology, UiB, headed by Professor Arne Graue, combines research efforts in the project "Integrated EOR for heterogeneous reservoirs". The project, led by centre postdoc Bergit Brattekås, began in the fall of 2014 and has so far produced 11 scientific articles, of which three have appeared in SPE peer-reviewed journals, and a book chapter. The baseline of the project is experiments on core scale, including numerical modelling of the fluid flow dynamics; with upscaling as a final goal.

The objectives are: 1) optimization of polymer gel and foam mobility control for use in-depth in porous formations, 2) combining the improved mobility control methods with EOR methods in specially designed, integrated processes. Integrated Enhanced Oil Recovery (IEOR) was previously shown to increase oil recovery from oil-wet, heterogeneous systems by significantly improving sweep efficiency. Oil recovery was observed to depend on the chase fluid, which largely controls the shape of the displacement front and thus the macroscopic sweep efficiency. In this project, mobility control is combined with surfactants, CO_2 or low salinity water in smart sequences for IEOR. The third objective is to include IEOR methods and process mechanisms in numerical simulators, in a way that is both representative and accurate; first on core scale, thereafter on reservoir grid and field scale.

CO_2-FOAM EOR FOR MOBILITY CONTROL IN ONSHORE FIELD PILOTS

The National IOR Centre of Norway participates in a collaborative research project headed by Professor Arne Graue at Department of Physics and Technology, University of Bergen. This project is an international collaboration between 13 universities/research institutions and 10 oil operators and service companies in Europe and the USA. It has been established to combine expertise with the objective to develop and test CO_2 Foam EOR with mobility control at large scale, to optimize CO_2 integrated EOR and aquifer deposition. Two field pilots will be performed within the international collaboration, where 5 PhD students, 30 MSc students and 8 professors at universities in 5 countries will participate.

Carbon dioxide has been successfully tested as EOR agent and used in fields, because of its properties of swelling oil, reducing oil viscosity and reducing residual oil saturation under miscible conditions. However, despite its high local displacement efficiency compared to other solvents, the process has poor sweep efficiency due to viscous fingering caused by unfavorable mobility ratio, and gravity segregation caused by density difference between injected and displaced phases.

The project is supported by The National IOR Centre of Norway with one PhD student, Mohan Sharma, who will participate in lab experiments at UiB, perform numerical simulations at UiS to predict fluid flow at field scale and spend research terms at Rice Univ. in Houston when he participates in the field pilots in West Texas.

Photo: One of the Centre collaborators from University of Bergen, Arne Graue, presenting at IOR NORWAY 2016. (Photo: Mari Løvås/The National IOR Centre of Norway)

INTERNATIONAL COLLABORATOR: LESLEY JAMES, MEMORIAL UNIVERSITY

Successful collaboration requires several key components; like-mindedness, trust and openness, and mutual areas of research to share and learn from each other. Collaborating with Merete Madland and The National IOR Centre of Norway at the University of Stavanger has all of those components.

Collaborating in areas of mutual interest is easy when the scope at The National IOR Centre of Norway is focused on improved oil recovery – the single objective. Well, that single objective is so multidisciplinary and diverse that collaboration is needed for bringing it all together. From reservoir engineering, mathematical modelling, physics, chemistry, geophysics, geochemistry, interfacial science, transport phenomena, chemical engineering, polymer rheology, to nanoparticles, and electrochemistry. One may ask, what discipline is not involved with IOR? We can look at recovery at any scale, from pore to field scale. What is the priority? How does it all fit together? The National IOR Centre's approach is broad and all-encompassing because it needs to be. Improved oil recovery is ever more important to effectively and efficiently recover oil and gas reserves from Norway, Canada, and globally.

Canada's east coast offshore oil accounts for only 6% of Canada's conventional oil production, 19% of the country's conventional oil reserves, and exploration being pursued even with current oil prices. While Canada's offshore oil and gas development is not nearly as mature as offshore Norway, both countries share more similarities than differences. Our weather, climate, and landscape are similar as is our food and love of nature. I feel very comfortable and at home in Norway and through this and other collaborations in Norway, visits and discussions take place several times a year.

Our objective at the Hibernia Oil Recovery Lab at Memorial University of Newfoundland is to maximise recovery from our offshore oil fields much like The National IOR Centre of Norway. The similar goals makes it easy to collaborate. Common objectives include maximizing recovery at all scales taking into account pore scale recovery and field scale sweep efficiency. Our producing light oil offshore fields are generally compartmentalized sandstone. This year, first oil is expected at Hebron, a more heterogeneous reservoir that is upward fining with increased calcite cements and medium crude. Our need to understand the fluid-fluid and fluid-rock interactions such as wettability alteration, improving sweep efficiency, and enhanced oil recovery (EOR) screening is essential to increase recovery.

Fluid-fluid and fluid-rock interactions effect pore scale recovery and larger field scale sweep efficiency. Work in this area is currently being carried out by The National IOR Centre of Norway and Memorial University where we focus on our specific reservoir characteristics, respectively. These common, yet parallel, goals have brought us closer to collaboration where we have discussed laboratory techniques, specific objectives, and received meaningful feedback. Our Hibernia EOR Lab has some overlapping but mostly complimentary experimental capabilities. Two custom high pressure laboratory scale reservoir-production systems are capable of slim tube minimum miscibility pressure measurements, continuous core flooding, and unsteady and steady state three phase relative permeability measurements along with a PVT viscometer, PVT apparatus, IFT/contact angle, centrifuge, mercury porosimeter, GC with simulated distillation, and our custom pore-scale micromodels.

Collaboration of cross sharing of best practices, operational and troubleshooting procedures, and reciprocal research visits for PhD students, highly qualified personnel (researchers), and faculty is highly valued by both Memorial and the UiS/ The National IOR Centre of Norway. Specifically, we are both learning and sharing our knowledge related to the interactions of polymers/smart water/nanoparticles with the specific reservoir mineralogy. Wettability and wettability alteration during EOR/IOR processes is another area of mutual interest along with screening studies. Leveraging each other's knowledge regarding the adsorption/absorption, diffusion/dispersion, and reactions at the pore scale is literally fundamental to our understanding. Our near-well coupled radial-axial flow and streamline models will hopefully be useful in the National IOR Centre's modelling efforts. Open and frank collaboration is possible because of the collaborative approach and culture of The National IOR Centre of Norway.

The National IOR Centre of Norway is achieving what many researchers hope to and I am very proud to affiliate with such a strong, multidisciplinary group. I am thankful for ongoing collaborations and look forward to continuing to work together in the future.

Photo: Lesley James from Memorial University during a visit to University of Stavanger. (Photo: Mari Løvås/The National IOR Centre of Norway)

Photo: In 2016 postdoc Pål Østebø Andersen and PhD students Irene Ringen, Tijana Voake and Jaspreet Singh Sachdeva met Lesley James at the 2016 International Symposium of the Society of Core Analysts (SCA) held in Snowmass, Colorado, USA. (Photo: Private)

NATIONAL COLLABORATOR: ANJA RØYNE, UNIVERSITY OF OSLO

The University of Oslo (UiO) has been a collaborator of The National IOR Centre of Norway since the start in 2013, and currently one PhD position at UiO is fully financed by the Centre.

Photo: Anja Røyne from University of Oslo presenting at IOR NORWAY 2016. (Photo: Mari Løvås/The National IOR Centre of Norway)

In the PhD project, we perform experimental investigations of pore scale processes using advanced nanoscale force measuring techniques, atomic force microscope (AFM) and surface force apparatus (SFA), to study how different brines influence the interaction force between calcite surfaces. This study provides essential input to theoretical models for IOR relevant pore scale mechanisms. The project is progressing through valuable discussions with IOR researchers at The National IOR Centre of Norway in Stavanger.

Our collaboration with The National IOR Centre of Norway place our study in a larger context of IOR processes at different scales, and fosters an environment where academia and industry can interact. The regular PhD workshops help to build a social and scientific community among the PhD students, and the annual IOR conferences, IOR NORWAY, in Stavanger serve as an arena for international communication of IOR research.

We hope that our ongoing collaboration can spur future projects in the nanoscale studies of fluid-rock and mineral-mineral interactions in the context of IOR.

INTERNATIONAL COLLABORATOR: PROFESSOR LAWRENCE CATHLES III

One of the collaborators of The National IOR Centre of Norway is Professor Lawrence Cathles III, of Cornell University, who met with researchers in the Centre for the first time while on sabbatical in 2007.

My collaboration with the leaders of The National IOR Centre of Norway started in 2007, when I was on Sabbatical at IRIS working with Willy Fjeldskaar on glacial rebound and basin modeling. During that stay I came into contact with Professor Madland who was working on the effect of seawater on the mechanical stability of chalk. I suggested that one possible explanation for this phenomenon was dissolution of the chalk. This quickly led to a beneficial collaboration between Professor Hiorth, Professor Madland and myself to understand the consequences of injecting seawater in carbonate fields like Ekofisk. Professor Hiorth and various members of his IRIS research group came to Cornell for week-long work sessions. The visits facilitated communications within Professor Madland and Hiorth's group. I contributed where I could, benefiting greatly from a first-hand view of what was going on in cutting edge oil field research. The thinking and work was grounded by the core experiments in Professor Madland and Hiorth's lab, and there was constant exchange of ideas and the design of new experiments. The idea was that the sulfate would combine with dissolved calcium to precipitate anhydrite, and the calcium would be replaced by dissolving calcite and precipitating a magnesium carbonate. The problem was that it was very hard to find any magnesium carbonate in flooded cores. A breakthrough came when Dr. Tania Hildebrand-Habel demonstrated that a calcite core flooded with seawater at 130°C for 2 years was completely replaced by magnesium carbonate behind a remarkably sharp migration front.

The founding of The National IOR Centre of Norway was seminal. It made tremendous sense to have a serious, broad (geophysical and geochemical) assessment of all the changes in chalk and clastic fields that have occurred during production of oil. In the three years of IOR operation I have mainly sought to implement nanoparticle methods for measuring the degree of fracture-control on flow in an oil reservoir. Because nanoparticles will not diffuse away from the fractures where flow occurs as much a chemical tracers will, the more rapid transit of the nanoparticles should reflect the degree to which flow is concentrated in fractures. The nanoparticles need to avoid retention, be stable at reservoir conditions, and their concentration must be accurately measured by their fluorescence. These remain challenging requirements for field tests, but even with their full resolution there will be a host of challenges to interpreting field tests, and many different kinds simultaneously deployed tracers are likely to needed. It therefore is invaluable to be able work with experts at the IFE in moving toward eventual multi-tracer field tests. Properly interpreted, such tests are one of the few and best tools we could have to measure how water moves through the reservoir rocks, and this capability is at the heart of engineering increased oil recovery.

The collaboration with The National IOR Centre of Norway has had another impact on my current activities. Last year Nestor Cordosa (UiS) and I wrote a proposal to INTPART (International Partnership for Excellent Education and Research) to run a 3 year course that would let a small group of selected students at UiS and Cornell interpret the chemical and physical changes that have occurred in parts of the Ekofisk field. This is just one of what I suspect are many examples of synergies between the IOR researchers in the Centre and Ekofisk experts that could open the door to unexpected and novel opportunities.

I have been at all the IOR NORWAY conferences so far, in-

Photo: Professor Lawrence M Cathles, III, from Cornell University has been collaborating with researchers in The National IOR Centre of Norway for a long time. He was invited to sum up the IOR NORWAY 2016 conference. (Photo: Mari Løvås/The National IOR Centre of Norway)

cluding the kickoff meeting in 2014. The technical content is of course outstanding and of great interest. But equally impressive is the degree to which high officials in the Norwegian government (including the Minister of Petroleum and Energy) attend, understand, and support the goals and efforts of the the Centre. What is happening at the Centre is vital to our ability to recover valuable oil resources, but perhaps even more valuable will be its demonstration of how a research project that involves academia, industry and government can be executed effectively. Employing a skilled and entertaining non-technical moderator, and including occasional artistic performances have been novel and delightful ways of enhancing information transfer. I look forward with anticipation to what will happen at this year's annual meeting.

THE VALUE OF COLLABORATION

BY PHD STUDENT MONA MINDE

Photo: Mona Minde is a PhD student in the Centre. She has taken advantage of the knowledge and experience from research institutions all over the world in her research on investigating the IOR mechanisms on core- pore and micro-scale. Photo: Mari Løvås/The National IOR Centre of Norway.

All PhD-students and researches in The National IOR Centre of Norway are encouraged to spend longer or shorter periods abroad collaborating with other research institutes and universities. In task 2, one of the most important objectives is to study EOR mechanisms and interpret how they function at nano- and micrometre scale. In-house microscopes and other analytical methods are widely used and applied based on our developed methodologies. However, it is vital for our researchers to have access to state-of-the-art analytical approaches found with our collaborators outside the country. To reach the goals of The National IOR Centre of Norway, we have to use the most sophisticated machine park available to contribute data on highest scientific level.

In 2016, we have had students visiting several laboratories, one of them being the Institute for Planetary Materials (IPM) in Misasa, Japan. I had the possibility to add to their research and learn from experts on highest level at this facility. Japan is a beautiful country and I really enjoyed the stay to visit Nina Egeland, who spent 6 months there, and learn about the IPM and the culture of Japan. Additionally, visits have been made to TU Freiberg in Germany, University of Bicocca-Milano in Italy and centre of excellence as part of the CNRS, 'LPICM' (École Polytechnique, Université Paris Saclay, France). Besides the first class data we receive in collaboration with these institutions; we also gain the possibility to get in touch with researchers from other research communities and disciplines. We find that in many cases, new insight and new investigation strategies are found when discussing our work with researchers and students with different backgrounds.

For my work, one of the most important visits this year has been to TU Freiberg to work with Bernhard Schultz and Sabine Haser at the institute for mineralogy. From my first visit, in 2012, they have always welcomed me and my fellow students visiting. They are happy to explain the work and methods and allow us to work independently with the analyses. In this way, we are able to fully understand the analytical method and to utilize the data to its full extent. The work has resulted in several co-authored papers, but maybe more important is the value of finding good co-operators, sharing the interest for the research and methodology. In Freiberg, a lot of the work is focused on the mining industry. It is exciting to see the work they are doing, and both Sabine and Bernhard always contribute to our work and ideas through asking questions and coming with suggestions. Often we forget to ask ourselves important questions as we work with the same material and objectives every day, while people "from the outside" may see things in a different light. I have in all visited Freiberg five times, and enjoy both the work, the company and the culture. Through these visits we not only gain competence and results, we make new friends, discover new places and learn more about other peoples food and culture. New ideas may be created, new approaches may be found, and new contacts may be formed.

Opening up our research and listening to other experts is in most cases an excellent opportunity to do research hand-on with experts to increase the value of our work, both for our collaborators and ourselves.

SELECTED RESEARCH STAYS 2016

PHOTO: UNSPLASH.COM

GREETINGS FROM JAPAN

Photo: «Cherry blossom season was a beautiful experience. The road continues like this for several kilometres ahead.» (Photo: Private)

Research assistant at The National IOR Centre of Norway, Nina Egeland spent six months in Japan. This is a travel letter from her stay at the Institute for Planetary Materials (IPM) at Okayama University.

Nine weeks have already passed since I first arrived in Misasa. Misasa is a small town with a population of 8000 located in Tottori Prefecture, western Japan. This is going to be my home for the next four months as I am working at the Institute for Planetary Materials (IPM) at Okayama University. The laboratory is one of the most well equipped and technically advanced solid-state geochemistry laboratories in the world. My study focuses on an improved understanding of the EOR mechanisms at pore scale by studying why, how, where, and which amount of new minerals preferentially grow when flooding with MgCl2 or any other seawater-like brine. We will perform basic experiments on artificial chalk cores together with exposed chalk samples.

THE RESEARCH

I am enjoying the opportunity to be involved in every step on the way in research, from sample preparation such as making thin sections to performing analyses with selected methodologies, and finally analyse and interpret the data. So far, I have made sample descriptions by analysing thin sections with FE-SEM and EPMA. The plan is to start the experiments in beginning of April. I have also done one oral presentation and attended an interesting conference, Misasa International Symposium 2016.

Last but not least, the most exciting aspect of this stay is the contact with top scientists and their way in executing research. Their foci are often extraterrestrial samples and scientific issues of global significance, mainly methodological problems. The interaction and level of creativity combined with opportunities to do basic research, free from any restrictions offers a very different view. The high motivation of the scientists in this institute is definitely liberated by this freedom but also implies extremely high responsibility of delivering exceptional results. A very different research environment and a very intense experience for a young scientist.

Photo: Research Assistant Nina Egeland spent six months working at the Institute for Planetary Materials (IPM) at Okayama University. (Photo: Mari Løvås/ The National IOR Centre of Norway)

THE CULTURE

For a person who had only tried sushi twice before moving to Japan, I must say that I am very impressed by the food, the quality and the variety. People are polite and welcoming, and the nature is beautiful. Japan is a fascinating country with many genius gadgets around. One example is that you would get a free plastic cover for your wet umbrella when staying in a hotel or entering a mall. Misasa is quite small, but famous for its hot springs. The guest house that I am staying at even has its own hot springs, one for women and one for men. The weather changes even faster here than in Stavanger. In a week, the temperature went from +20°C to -2°C and up to +15°C again. Fortunately, the weather became more stable from March on and I am very grateful for the chance to experience the cherry blossom season these days. This is one of the most important events in the Japanese calendar that nearly all Japanese people are waiting for. Having lived here for some time, I see more nuances in the general perception abroad of Japan as a high-tech country. Some examples are that it seems quite luxury to have more than three gears on your bike, the opportunities to book transportation online is a bit limited, and every Japanese get a designated stamp for signing important papers, such as financial documents. And the word 'no' does not really exist.

However, it is always interesting to learn new cultures, and overall I am enjoying Japan.

Sayonara!

THE SUPERVISOR AND COLLABORATOR: MEET ANDREAS STORDAL

Andreas Stordal works in Task 7 in Theme 2 in The National IOR Centre of Norway. He is currently supervising Yiteng Zhang who is a PhD student in the Centre. His second role is as a collaborator with TU Delft and TNO in the Netherlands where he spends about 2 months each year as a visiting researcher.

«For the last 3 years, I have visited TU Delft and TNO in Utrecht and worked closely with students and researchers. The collaboration has resulted in many publications on optimization within reservoir management,» he explains.

THE PURPOSE OF THE RESEARCH

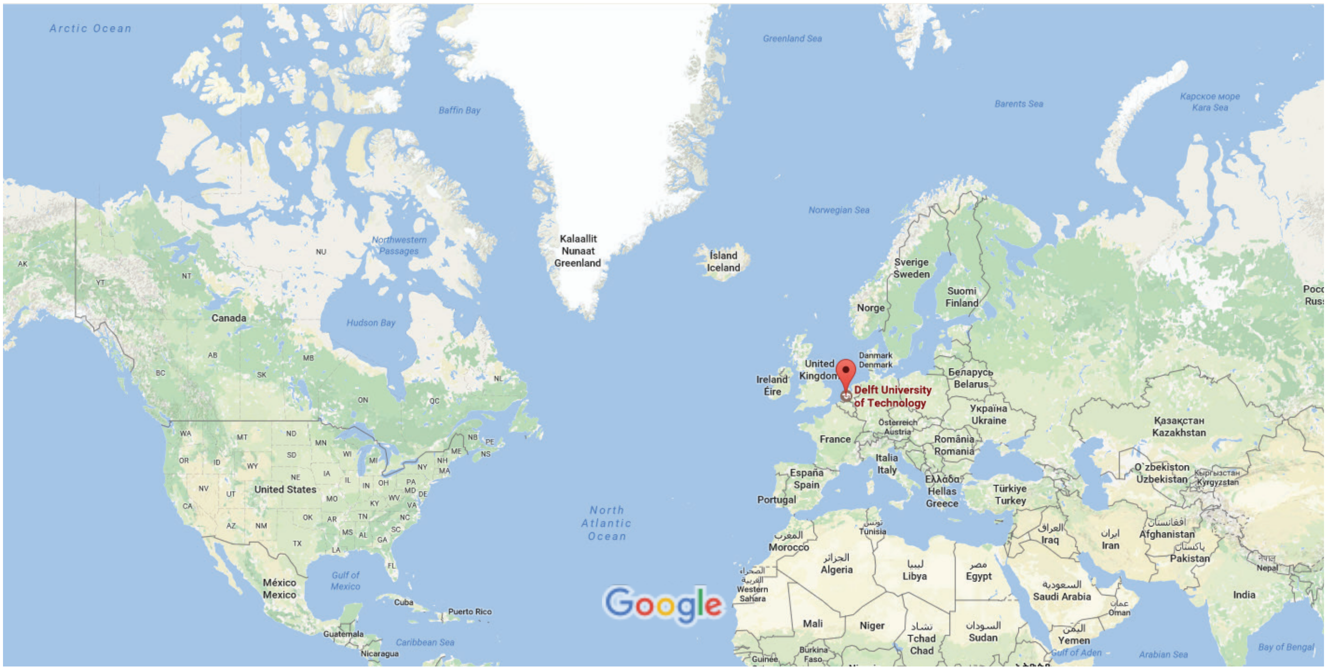
«The main purpose of our research is to provide companies with efficient and robust optimization algorithms that are gradient free and independent of the reservoir simulator that the companies use,» Stordal says.

«The extensive use of commercial simulators with limited functionalities and unavailable source code force many companies to view the simulator as a black box. Hence developing algorithms that only work with input/output is of great interest,» he continues.

VISITING COLLABORATORS

From mid-August until mid-October 2016 Stordal was on his yearly visit to the Netherlands, where he spent two days a week at TNO in Utrecht and the remaining three at the University in Delft.

«In addition to working with a master student on estimation of relative permeability curves, I was working with Rahul Fonseca (TNO) and Rafael Moraes (TU Delft and Petrobras)



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on improving the efficiency of our optimization algorithms. We are still running simulations on the cluster in Delft, but so far the few results we have look positive,» Stordal says.

THE BENEFITS OF COLLABORATION

«I think collaboration and joint publications with TU Delft and TNO can help make The National IOR Centre of Norway more visible internationally,» Stordal says, and continues:

«I believe that being present and working closely together gives the Centre and its researchers an advantage when the collaborators are looking for research partners on their projects.»

«Also, from my own experience, collaborating with other institutes can increase the knowledge of the researchers within the Centre,» he says.

On the question on how his research is relevant, Stordal replied:

«A few years ago we discovered that the algorithm we are using for optimization could be seen as a special case of a broader class of algorithms. This opened up a cascade of new aspects to look into, both practical and theoretical. This discovery has helped increase the understanding of the method, and it has also lead to several extensions that has improved the stablity and efficiency of the method,» he explains.

POLYMER CHARACTERIZATION ABROAD

Photo: Culture and learning. Here a castle from the city of Pau in France. (Photo: Private)

PhD student Eystein Opsahl spent his summer working with polymer characterization in Pau, France.

Polymer chemistry has been around for some time. Today, polymers are employed widely in almost every object we surround ourselves with. Some polymers are water soluble such as gelatin, whereas some are soluble in organic solvents such as Styrofoam. Technically speaking, there are no important differences between those two polymers except from their usage. In EOR we use variants of water soluble polymers analog to the Styrofoam, except that they are water soluble.

So traditionally we never cared to measure anything else than that which is essential to the polymers function. In EOR for example, the only property we are interested in is its ability to viscosify water at various conditions. Easily measurable with a simple rheometer. For some areas of research, precise polymer characterization is critical. In toxicology, environmental chemistry, detailed knowledge about size and structure supersedes the same polymers ability to viscosify water.

For a long time we have been able to decipher any polymers chemical composition, as in how much carbon, oxygen it contains and how its chemical backbone might look like. Nonetheless, measuring the actual size and chain length of any given polymer has been giving researchers headaches for the longest time. Effectively hindering advances and understanding on this front. I.e. relating structure to activity, an important piece of the environmental puzzle.

But thanks to modern computing and hardware, we have recently been given access to a world of polymer analytical chemistry previously thought to be mostly inaccessible. With the aid of modern light scattering equipment together with ever better separation techniques we are now mostly able to determine the absolute size (molecular weight) of a polymer, even a mix of polymers can to some extent be effectively resolved. Light scattering can even be used to determine the conformation of a polymer.

Before this, one had to rely of relative techniques, such as gel permeation chromatography, that was very prone to a number of phenomena that I am not going into detail about this time over. Let's just say for now that any other method than light scattering for polymer weight characterization is very unreliable.

Anyhow, such light scattering equipment have developed alongside computers to become commercially available in a digestible price range. What is not commercially available, hardly available at all I would wager, is the niche experience

Photo: IPREM, where I worked, in the fancy building to the left. (Photo: Private)

Photo: Me and my friends in the Pyrinees. (Photo: Private)

Photo: Greetings from Boulevard des Pyrenées. (Photo: Private)

Photo: Le tour de France visits Pau. (Photo: Private)

needed to use such equipment without falling into the abundant pitfalls. This is definitely scarce resource in Norway, even in the Nordic countries.

SNF Floerger, a leading global supplier of industrial polymers based outside of St. Etienne in the middle of France have built considerable expertise in this area. They are collaborating closely with the University of Pau, in the south of France, in order to develop new polymers and to characterize the polymers SNF makes. As such, there is a number of researchers concentrated within a small are with the necessary know-how. As a result, this is where I ended up for my international exchange period.

And boy did I learn. Initially I had one week of training with the supplier of our light scattering equipment under my belt, however, that was far from enough. I'd reckon a master in polymer chemistry with focus on this equipment alone would be the bare minimum required to operate it with somewhat success. Thankfully, I was in the best hands for 5 months, where was allowed to play around and teach myself the ins and outs of the equipment. Now just some few months after my return to Norway I begin to see the fruits of my exchange ripening.

Now, I can with confidence say that I am now autonomous and can continue the learning process on my own. Something that I could never have done if it wasn't for my time in Pau. Here at the University of Stavanger we have a very limited research environment around polymers, I am almost alone. So the benefit of becoming autonomous is priceless. All in all, I got what I came for, even if I weren't able to produce publishable result while I was there. But that I can now do on my own.

That's not all though, besides the obvious scientific benefit of this visit. The social frame that surrounded this visit has been a blessing. I've been on exchange before with varying success. However this time, it was. Bearn, the region in which Pau lies, is inhabited with the most likable people on earth.

I do not know any French, or at least I didn't, the French do not speak English very well, and even less Norwegian. This made the much famed French bureaucracy hilarious.. However, the friends that I made in Pau. These people really know how to care for each other and how to live a good life. They helped me with everything that I needed help with, thought me French on a daily basis and showed effort to be inclusive towards me and other newcomers. It made my stay a very pleasing and unforgettable one. These friends are also researching polymers, so I'll bet that I'll meet them again in some corridor somewhere in the world. 10/10 would do again. And lets not get started on the scenery surrounding Pau, the Pyrenees, the vineyards, the cultural heritage, the beaches, the weather, that would all impress Slartibartfast. I was sad but happy to finally ride into the sunset on my iron horse towards Norway on a chilling October night of 2016.

ECONOMY 2016

OPERATING INCOME AND OPERATING COSTS 2016
(All numbers in 1000)

Remaining as per 31.12 previous year	-3 586
UiS - own contribution	14 107
The Research Council of Norway	11 194
User partners	20 000
User partners - in kind	2 305
International - in kind	796
Other income	694
Total operating income	**45 510**

Payroll expenses	21 508
Procurement of R&D services	19 031
R&D services - in kind	2 305
International R&D services - in kind	796
Other operating expenses	2 008
Total operating expenses	**45 648**

Operating profit	**-138**

COMMENTS TO OPERATING INCOME AND EXPENSES IN 2016:

- Negative operating profit for NOK 3586 was transferred from 2015 to 2016.
- Income from the Research Council of Norway includes NOK 4527 for 2015 and NOK 6666 for 2016. NOK 3333 will be transferred from RCN in 2017 to cover costs for 2016.
- Income includes payments from 10 user partners. They each paid NOK 2000 for 2016.
- Halliburton, Schlumberger, DTU, ISEI and CU each contribute by providing work in kind.
- Other income relates to IOR NORWAY 2016.
- Payroll expenses includes IOR Management, administration, R&D, PhDs 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 2016 etc.
- Negative operating profit for NOK -138 is transferred to 2017.

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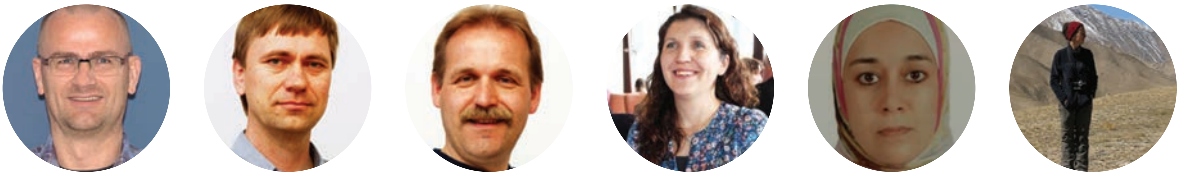

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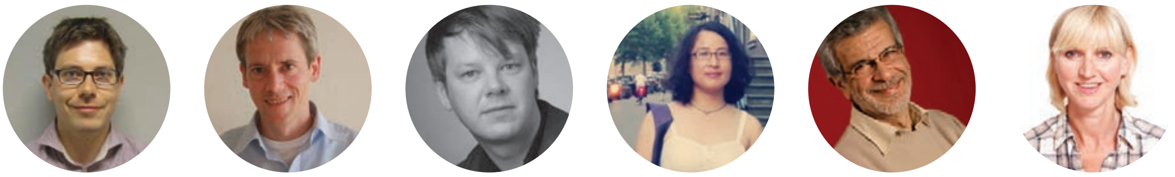

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