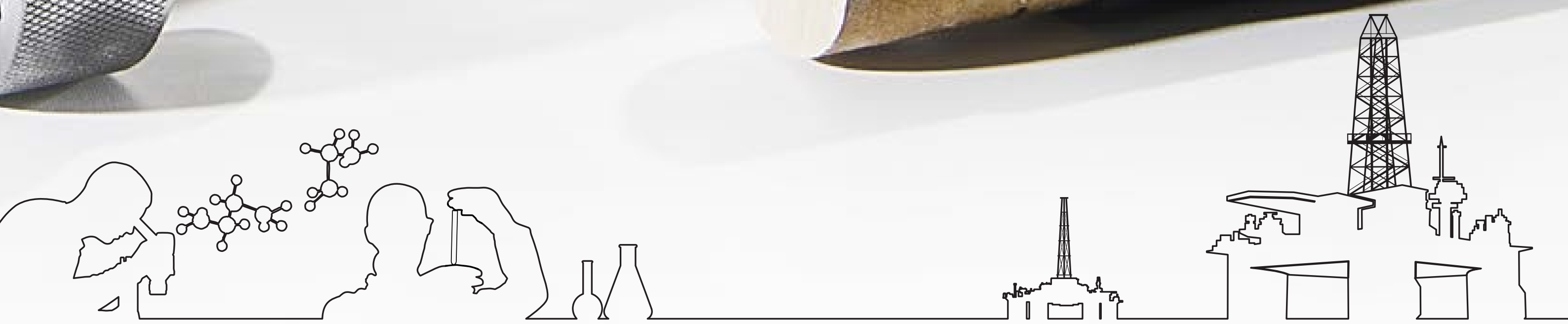
Technical University of Denmark

Danish Hydrocarbon Research and Technology Centre

ANNUAL REPORT 2016



Centre for Oil and Gas - DTU

The Danish Hydrocarbon Research and Technology Centre

Cover picture of core holders: In December 2016, DHRTC opened their first laboratories in building 375 at DTU. With the new laboratories, DHRTC has created an important framework for the experimental and interdisciplinary activities that go on in the partnership and the collaboration relating to the laboratories can be even more extended now and as we move forward. Photo: Joachim Rode.

Annual Report 2016
Danish Hydrocarbon Research and Technology Centre (DHRTC)

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DHRTC is well underway

Two years ago, the Danish Hydrocarbon Research and Technology Centre (DHRTC) opened, and I'm delighted to invite you inside the Centre's first annual report.

It was with excitement and high ambitions that we opened our doors in September 2014. Excitement because it was the first time in Danish history that an attempt was made to establish such a close, focused partnership between universities, disciplines, and the business community on creating new knowledge and innovation within oil and gas recovery. High ambitions because they are necessary if DHRTC is to live up to its raison d'être. DHRTC has been established to deliver both substantial research, innovative solutions, and talented employees. This will contribute to ensuring that in the future it will be feasible and profitable to recover more oil and gas from the Danish part of the North Sea than is possible today based on our current knowledge and technology.

It has been exciting to establish a collaboration between researchers at not less than five research and education institutions while coupling research closely with the needs and challenges that the oil industry is facing in the North Sea.

The first couple of years have generally been spent on starting things up and systematizing them. We have defined the issues that the Centre's research and innovation will initially be focusing on. This combination has resulted in the Advanced Water Flooding research programme which attempts to find new ways to recover a larger share of the oil by new technology solutions based on a better understanding of critical elements in physics of oil-bearing chalk layers. In addition, the Cost Transformation programme has been established. It focuses on reducing the costs of operations and equipment above sea level. We have rolled out our first interdisciplinary and intersectoral projects, and we are already seeing signs that joining forces across disciplines, institutions, and practices releases a certain energy and high quality in the work performed.

In this connection, I would like to express my sincere thanks to our colleagues and partners at Aarhus University, Aalborg University, Technical University of Denmark, GEUS, and the University of Copenhagen. I would also like to extend my appreciation to the parties in the Danish Underground Consortium (DUC), Maersk Oil, Shell, Chevron, and Nordsøfonden, for your trust in granting funding of DKK 1 billion to the Centre's first ten years of operation. Thanks also to all parties for their willingness to share their knowledge, data, and enthusiasm. With a trusting and dynamic collaboration between the research and the business community, we are able to progress towards our shared goal of a truly application oriented research centre. We are now well underway and ready to pursue the next level of our ambitions.

Bo Cerup-Simonsen
Centre Director

"With a trusting and dynamic collaboration between the research and the business community, we are able to progress towards our shared goal of a truly application oriented research centre"

Photo: Carsten Albrechtsen

Photo: Joachim Rhode

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Photo: Mærsk

Photo: Mikal Schlosser


Photo: Maersk

Hoda Javanmard, research assistant, working in the new DHRTC laboratories. Photo: Joachim Rode.

DHRTC creates results through interdisciplinary research and innovation

The Danish Hydrocarbon Research and Technology Centre (DHRTC) was set up to help increase the recovery of oil and gas in the Danish section of the North Sea on a commercially viable basis and within the frameworks of environment and safety. The centre's vision is to engage in interdisciplinary international level research and innovation in collaboration with the business community.

DHRTC was founded in 2014 based on a DKK 1 billion grant from the partners in the Danish Underground Consortium (DUC). In practice, the research activities are managed by the Danish Hydrocarbon Research and Technology Centre at DTU, which at an overall level coordinates and prioritizes the centre's research and innovation in collaboration with the centre's five partners: Aarhus University, Aalborg University, DTU, GEUS, and the University of Copenhagen.

The Danish Hydrocarbon Research and Technology Centre at DTU is also responsible for processing the knowledge generated by the research with a view to developing commercially viable solutions – which includes requirements to adhere to the high industry requirements of environment and safety. The aim is solutions at prototype level, i.e. step three on the TRL scale (Technology Readiness Level), which indicates the degree of technological maturity with a total of eight steps.

Two-thirds of the oil is left

DHRTC was established at a time when Denmark had been recovering oil and gas in the North Sea for almost 50 years. Denmark became self-sufficient in 1993, and up until 2004 pro-


Charlotte Lind Laurentzius, programme manager, and Mojtaba Seyyedi, postdoc, DHRTC. Photo: Joachim Rode.

duction increased steadily to more than 20 million cubic metres of oil a year. Since then, both oil and gas production have been halved, mainly due to the natural decline in production rate in maturing fields (*cf. Oil and gas production in Denmark. Danish Energy Agency, 2014*).

It has taken numerous successful innovative efforts over the past 50 years to bring the expected ultimate recovery to its current state. For instance the successful introduction of water injection in chalk fields as well as horizontal drilling and completions have enabled significant leaps in the ability to produce from the Danish North Sea. Initially it was considered a breakthrough to be able to even recover 5 per cent but today certain fields have reached an expected ultimate recovery of around 40 per cent and the average over the entire portfolio of DUC fields is 28 per cent. But even if great innovations with successful scientific and technology solutions as well as safe and environmental operations have brought the recovery a long way, there is still expected to be 72 per cent left, when the operations are terminated. So we are in a situation where much has already been tried, much has been successfully achieved but production is declining and operational costs are increasing.

So we are left with the challenge of working out: How much can the expected recovery be increased through research, innovation, and new recovery methods? And to what extent is it possible to cut costs through smart ways of operating, developing, and maintaining the production facilities?

DHRTC's ambition

At the same time, DHRTC is helping to facilitate more international-class research in Denmark in the fields of geology, geophysics, and geochemistry. In addition to the research grants resulting directly from the DUC's investment of DKK 1 billion over ten years and the universities' own funding to among others facilities and central support functions, the centre is helping to generate additional grants. Thanks to the basic funding from the DUC, it is possible for researchers to obtain additional funding from other sources. The DUC's grant thus supports volume and quality in R&D at Danish research institutions and enterprises.

For the business community, the hope is that the investment in research and innovation will do more than just pay for itself. If the work of DHRTC means that recovery increases by just 0.1 per cent, the investment in the centre will have paid off. However, the ambitions are higher than that. It is DHRTC's ambition that by 2020 it will have identified technologies that can lead to the recovery of an additional 100 million barrels of oil equivalent (MMBOE).

DHRTC goal

The goal of DHRTC is to establish a well-functioning framework for international research and to build a solid foundation for interdisciplinary research across research institutions. Against this background, new technological and conceptual solutions are identified that boost oil and gas recovery in the Danish section of the North Sea. Moreover, DHRTC educates and attracts highly qualified employees for both research and business.

Overview: Danish Hydrocarbon Research and Technology Centre

Research Programme

AWF • Advanced Waterflooding
- about increased oil recovery from the Ekofisk and Tor formations through research into these two chalk strata in the North Sea.

- Demo model AWF 1 Development of Ekofisk (Pilot: Dan/Kraka)
  - Recovery Processes on Core Scale
  - Reservoir Simulation
  - Reservoir Fluid Characterization
  - Improved geomodel with deterministic fracture representation and outcrop analogue information
  - Seismic Geomorphology and Reservoir Characteristics of Chalk Fields
- Demo model AWF 2 Improved Sweep in Deep (Pilot: Halfdan)
  - Radial Jet Drilling
  - Composite Coiled Tubing

Research Programme

CTR • Cost Transformation
- about increased oil recovery through a paradigm shift on the cost side based on research into oil platform structures and operations.

- Demo model CTR 1 Increased Water Injection Availability (Pilot: Dan and Halfdan)
  - Multilevel Flow Modelling (MFM) of Design, Decision and Plant Processes
  - Big Data Methods for Identifying Cause and Effects for Downtime
  - Laboratory Testing at AAU-Esbjerg and development of filtration methods
- Demo model CTR 2 Transformation of asset Cost (Pilot: Gorm)
  - Cost Reduction by 4D Maintenance Planning (feasibility)methods
  - Scale and Corrosion
  - Well Integrety
  - Well Conformance
- Demo model CTR 3 Extend Life of Potential Hub Structures
  - Structural Integrity & Monitoring
  - Extreme Waves
  - Risk Modelling

Research Programme

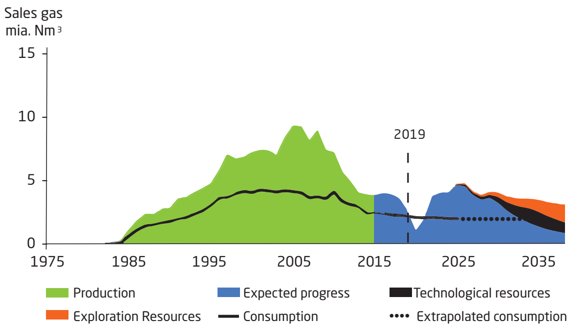
TRD • Tight Reservoir Development
- on increased recovery from the Tuxen formation through research into the deep chalk stratum in the North Sea which is characterized by less permeability than the Ekofisk and Tor formations.

DHRTC's research is organized into three programmes, each with its own theme. Under each programme are so-called demo models that define specific challenges which the research must help to address — organized into work packages. All three levels are shown in the graphic.
The research is conducted on the basis of a DKK 1 billion grant from the partners in Danish Underground Consortium, which comprises the Maersk oil, Shell, Chevron, and the Danish state's oil and gas company Nordsøfonden. Programmes, demo models and examples of the research are described in more detail on the following pages, and at the back of the publication a complete list of the research projects taking place under the auspices of DHRTC is shown.

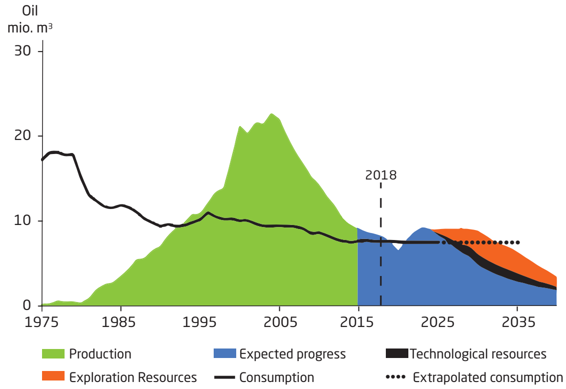
Denmark is dependent on fossil fuels

According to the current energy policy, Denmark will be dependent on fossil fuels until 2050. In other words, Danes will need oil and gas for another 34 years.

Gas Production in the North Sea



Oil Production in the North Sea



Since Denmark started recovering oil more than 40 years ago, one of the political objectives has been that Denmark should to the greatest possible extent be independent of oil and gas imports from other countries. Denmark succeeded in becoming self-sufficient in 1993, and has been so ever since.

According to the latest forecast from the Danish Energy Agency — published in August 2016 — Denmark will remain a net exporter of oil up to and including 2018. In 2019 and 2020, consumption is expected to exceed production. However, it is then estimated that Denmark will again be a net exporter up until 2032, when factoring in technological resources and exploration resources. The technological resources are the oil which should be possible to produce thanks to the use of new technologies. The exploration resources are an estimate of the oil which will be recovered from new discoveries.

For sales gas, Denmark is expected to be a net exporter for four years up to and including 2019. Consumption is expected to exceed production in 2020 and 2021. If including the technological resources and the exploration resources, the Danish Energy Agency estimates that Denmark will be a net exporter of gas after 2021 and up until after 2035.

Increased recovery from the Ekofisk and Tor formations

Advanced Water Flooding

How is it possible to recover more oil from the chalk in the North Sea? This is the key question in DHRTC's research programme Advanced Water Flooding (AWF).

The Ekofisk and Tor chalk formations have for many years played a central role for Danish oil recovery, as they still contain significant oil and gas volumes. The research programme Advanced Water Flooding is focused on developing new methods for recovering a larger share of oil. One of the challenges is to increase the sweep efficiency in the uppermost oil-bearing chalk stratum, the Ekofisk formation, to the same high level as in the underlying Tor formation. The challenges are due to the properties of the chalk. The porosity of the chalk in the Ekofisk formation is the same as that of the Tor formation, but it is less permeable. The reason for this is that the Ekofisk formation was formed by unicellular planktonic chalk algae, coccolithophores, approx. 60 million years ago, and these coccolithophores are smaller than the ones that built up the Tor formation approx. 70 million years ago.

In Ekofisk, the research focuses on:

- learning more about the properties of chalk
- the possibility of using fracturing – small cracks in the chalk to increase recovery
- new methods for forcing the oil out by injecting water, chemicals, or bacteria – Enhanced Oil Recovery.

In the Tor formation, the challenge is finding technological solutions that enable more oil to be recovered from deep, compact chalk strata. The research focuses on:

- the possibility of using hydraulic fracturing
- the development of new drilling and fracturing tools and new applications for existing tools

For both the Ekofisk and Tor formations, computer simulations and models are being developed and the most promising methods could be selected for testing in the North Sea.

Photo: Joachim Rode

Core samples cut out of the drill cores, which have been removed from the rock in connection with the drilling of wells.

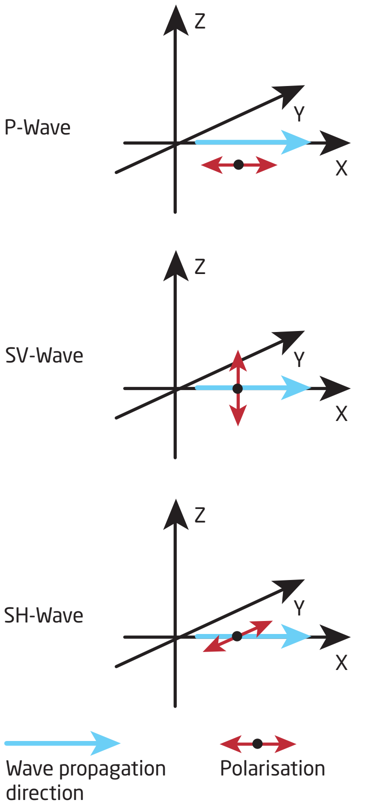
New seismic method creates close-ups of chalk

Using a combination of two seismic measuring methods, Janina Kammann, a geophysicist, creates new and detailed knowledge about what chalk strata look like. The new 'close-ups' mean that the oil industry has more detailed information on the geology and geophysics in the oil-bearing strata.

There is much more to chalk than meets the eye. There are big differences in how porous or impermeable the oil-bearing chalks in the North Sea are. For the oil industry, it is important to know the physical properties of the chalk strata at particular locations, because this has a bearing on how to recover the oil and gas, and whether it can be viable.

So far, the seismic methods available for studying the chalk on land have resulted in images of the subsoil with a resolution of three to ten metres. Now, the ambition of a new interdisciplinary research project financed

PhD student Janina Kammann with the compact and portable Surface Vibrator Source ElViS III machine in a chalk quarry near Aalborg. Photo: Carsten Albrechtsen



Seismic measurements with P and S-waves. Illustration: Janina Kammann

by DHRTC is to describe the chalk strata down to the one-metre scale.

To begin with, the work will be carried out on land, at Stevns Klint on Zealand and in a chalk quarry at Rørdal near Aalborg.

"It's much easier and less expensive to carry out seismic measurements on land compared to at sea, and we are very lucky that the chalk strata at Stevns Klint and in Rørdal resemble the formations in the North Sea where the oil is found. This means that knowledge obtained onshore is also applicable for offshore locations," says Janina Kammann, a geophysicist and PhD student at the Department of Geosciences and Natural Resource Management at the University of Copenhagen.

She is working on combining two seismic measuring methods, which together will produce new, high-resolution images. It is the first time that the method is being used to describe the porosity of Denmark's chalk formations.

Interdisciplinary collaboration

When geophysicist Janina Kammann works in the field with the university's new measuring equipment, she is accompanied by geologists from the Natural History Museum of Denmark. The geologists take samples of the subsoil, which are used to qualify the seismic measurements.

Subsequently, the researchers involved in the interdisciplinary project compare the new knowledge about the chalk strata on land with existing knowledge about the geology of the North Sea.

Eventually, this will lead to geophysicists at the Niels Bohr Institute preparing so-called geostatic models. This is a sort of map of the geology of the North Sea, which the oil industry can use in its efforts to recover oil and gas.

Surface vibrator source ElViS III

Basically, Janina Kammann obtains her results by both stamping on and

Janina Kammann's Ph.D-project

Near-surface seismic investigation of reservoir rocks. The reflection seismic method is widely used in both offshore and onshore mapping and description of hydrocarbon reservoirs. This projects studies onshore rocks that are analogous to rocks in the North Sea that form reservoir to oil and gas using P- and S-wave seismic data recording. As part of the project the PhD student will set up and carry out testing of the seismic instrumentation. The P- and S-wave data sets are integrated with borehole data and geological mapping and used to construct new models of key rock physical parameters, which are used in new reservoir models.

DEMO MODEL AWF1

Development of Ekofisk

The demo model is inspired by the Kraka field, where the oil is found in a chalk layer in the subsurface, which is called Ekofisk. The oil produced in this field is today brought to the surface by a naturally occuring over pressure in the resevoir. However, the pressure is declining quickly, and therefore only a very small amount of the oil will be recovered. In the Kraka field, it is expected that only about 12 per cent of the oil can be recovered based on the natural over pressure. By pumping water down into the oily geological strata, today it is perhaps possible to squeeze more of oil from the reservoir.

DHRTC's hypothesis

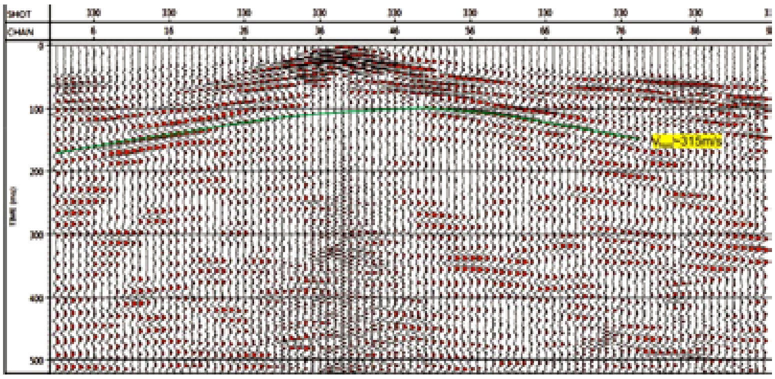
- Changing the chemical properties of the injected water can increase oil production
- Optimizing the positioning of the wells in relation to the water and oil as well as the properties of the chalk strata can increase oil production

DHRTC research

In order to achieve the objective of improving the existing water injection technology, DHRTC is conducting research into, for example:

- The identification of suitable IOR/EOR methods
- The working process in connection with the development of a DFN geomodel
- Outcrop descriptions for the calibration of models for subsurface fractures
- Processes for water-based recovery and laboratory-scale experiments
- Core flooding models for use in laboratory-scale experiments

Data from Stevns Klint



Shear wave seismic data from Stevns Klint of a 'shot'. X-axis: Geophone registrations 0–90 metres from the source. Y-axis: Time in metres/second.
Source: 'High resolution P- and S-wave reflection seismics linked to log data in chalk reservoir analogues at Stevns, Denmark.' Danish Hydrocarbon Research and Technology Centre Technology Conference 2016

shaking the surface of the ground with a compact item of portable equipment called the Vibrator Source ElViS III. The vibrator weighs just 35 kg and produces acoustic waves. When ElViS III stamps, the movement is transmitted as compression waves, or P-waves. When ElViS III shakes the surface from side to side, the movement is transmitted as waves that 'twist' the surroundings, and are known as shear or S-waves. The movements of the waves are registered by 96 geophones, which are small cylinders that are placed in a line at one-metre intervals for almost 100 metres.

This means that the equipment is able to collect geological data down to a depth of 100 metres. When Janina Kammann then processes the data on her computer, she is able to show images of the chalk strata at Stevns and in Rørdal down to a resolution of just one metre.

"The combination of P and S-waves makes it possible to obtain information about the petrophysical properties of the chalk. Previously, it was usually only possible to carry out measurements on land using P-waves, i.e. compression waves, and this provides less information about the physical characteristics of the chalk strata," explains Janina Kammann.

Chalk strata with different properties

On the face of it, the chalk strata appear very homogeneous, but the geologists' analyses show that differences in the size and shape of even micron-sized grains (1 µm = 0.001 mm) have a bearing on porosity. The oil industry is therefore interested in learning more about the properties of the chalk strata.

"Out in the North Sea, the oil is found in chalk formations that resemble those onshore. However, the 'voids' in the chalk, where the oil is located, are very different from place to place. This affects permeability, i.e. the ability of the chalk to transport gas and oil, and it is an important detail for the industry," says Professor Lars Nielsen from the Department of Geosciences and Natural Resource Management at the University of Copenhagen.

He is PhD supervisor for Janina Kammann, and one of the three leaders of the multidisciplinary research project which is lasting up to four years and includes contributions from 11 members of academic staff at the University of Copenhagen and one or two postdocs at DHRTC. The other two leaders are Professor Lars Stemmerik from the Natural History Museum of Denmark and Professor Klaus Mosegaard from the Niels Bohr Institute.

"Being able to participate in such a big interdisciplinary project through DHRTC is completely new. However, this interdisciplinarity is vital for us to fulfil the goals we have set ourselves. None of us could do it just working in our respective academic groups," says Lars Nielsen.

The project is also basic research

Natural science researchers are usually driven by wanting to find out more about basic aspects of the natural world, physics, and mathematics. This is also the goal here, but at the same time the ambition is to develop a new statistical model for the benefit of the oil industry, i.e. a kind of geological map of parts of the North Sea. This is what Professor Klaus Mosegaard is working on:

"The aim of all the DHRTC projects is to increase oil production in the North Sea, and out there people are interested in having as detailed an image of the oil reserves and the geology as possible. Today, we have quite a lot of knowledge from, among other things, drill holes and seismic surveys, but in fact the picture is relatively unclear," explains Klaus Mosegaard.

Klaus Mosegaard and his colleagues at the Niels Bohr Institute and DHRTC are working on new, interactive maps of the chalk strata in the North Sea with a resolution down to one metre. They are doing so by combining existing knowledge from the North Sea with new knowledge from, among other things, Janina Kammann's PhD project. In addition, probability calculations are also used.

"At the end of the day, a geologist or geophysicist should be able to ask the model what the geology looks like at a particular resolution at a given location at a depth of say 3,312 metres. Then the model will come up with an answer, and at the same time state how much uncertainty is associated with the calculation," says Klaus Mosegaard, who expects the first maps to be ready before 2020.

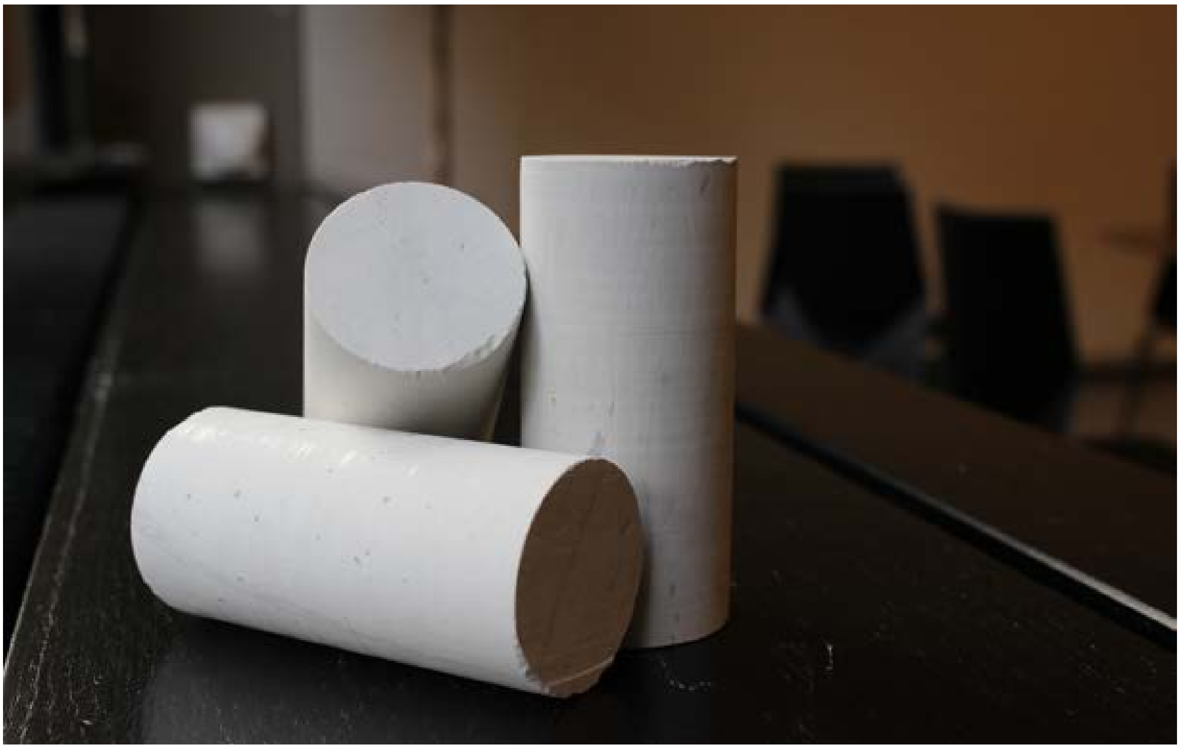
Postdoc Amalia Yunita Halim in the laboratory. Photo: Joachim Rode

CT scanning of core plugs contributes to more efficient oil recovery

Out in the North Sea, it is not possible to examine what exactly takes place in the reservoir when the oil industry injects water and in future perhaps adds chemicals, modified water, or bacteria to increase recovery. Therefore, researchers from DHRTC have taken core plugs to the laboratory and CT-scanned the recovery process.

The core plug is just 4 cm in diameter and 9 cm long. However, despite its size, this small cylinder of chalk from the North Sea may well contain secrets that are invaluable for the oil industry. In the laboratory, researchers from DHRTC use a method that mimics the actual recovery process in the North Sea, and they have improved the CT scanning of the process to follow the oil saturation inside the core sample. For this, they use bits of core plugs which are carefully chosen so their porosity and permeability are largely similar to the conditions in the most oil-saturated rock strata — several kilometres beneath the seabed.

By means of the CT scan, the researchers can show 3D images of what happens inside the chalk at millimetre scale when you inject water and in future perhaps chemicals, modified water, or bacteria to increase oil recovery. The idea is to test different EOR (Enhanced Oil Recovery) methods in the laboratory and to arrive at the best method. In this way, the research could contribute — at the end of the



The core samples are cut out of the drill cores, which have been removed from the rock in connection with the drilling of the wells. They measure 4 cm in diameter and are about 9 cm long. Photo: Mirhossein Taheriotaghsara, DHRTC

Work in the laboratory

Conducting the experiments with core samples takes three to four months. These are parallel, comparable experiments, with some of them being CT-scanned along the way. During the scanning, the following happens:

- All dry core samples are CT-scanned to establish their 3D porosity
- Saturation with brine which matches that found in the specific oil reservoir which the core sample comes from
- Saturation with oil, so the core sample now contains both oil and brine
- The EOR process in the core sample is scanned several times during the process

The CT scans must be corrected, as the X-ray tube in the scanner becomes hot and moves during the scanning. This changes the image values. To correct this, a pressure tank is used in which the core sample is placed as a reference material. The materials have a known CT value, and when their CT value deviates from the expected value, the entire image can be corrected according to the right value.

The bore samples are placed in a rubber sleeve in the pressure tank. They can therefore move slightly between the scans as the liquid is injected. Within medical image analysis, it is a well-known problem that images taken at different times or using different scanners have to be combined so they match as precisely as possible—so-called co-registration. These methods have been adapted so they can be used on bore samples.

The raw images from the scanner have a noise texture which makes it impossible to obtain quantitative information by deducting them directly from each other. The images are smoothed out instead using a Gaussian filter.

day — to the industry being able to recover more oil.

"The aim is to visualize what is actually happening inside the core sample when we study a recovery process," says Amalia Yunita Halim, a postdoc at DHRTC. "Often when you use an EOR method on a core sample in the laboratory, you can actually see that oil is being produced. However, you don't actually know how the oil moves inside the core sample, and where in the core sample oil remains. Thanks to the improved image analysis provided by CT scans of the dense chalk core samples, it is possible to see whether the oil actually moves, and where it is trapped, and use this knowledge quantitatively without having to dope one of the fluids with contrast agent."

Smart water as lubricant

The scientific work with the CT scans focuses on examining which EOR methods might be worth using in order to improve the sweep efficiency and reduce the residual oil saturation in an oil field.

"It's much easier to choose the best EOR method when you can see what is happening inside the chalk and at the same time measure how much oil comes out. If you only measure the oil, it's like working in the dark," says Anders Nymark Christensen, a postdoc at DHRTC.

Initially, the scientists are focusing on different combinations of brine as an EOR method — so-called 'smart water'. The researchers' hypothesis is that it would be cheaper for the industry to use a variant of water rather than adding various chemicals. The price has to be low, as the oil industry will need to use huge volumes. In 2014, about 35 million cubic metres of sea water were injected into the rocks under the North Sea as part of the work to recover oil," explains Anders Nymark Christensen:

"So, even if, as part of EOR, you needed to add just 100 ml of a chemical, for example, to one cubic metre of water, it would still add up to large quantities," he says.

The two researchers are part of an ever-growing team of more than 10 people who are trying to find EOR methods that can increase oil recovery, particularly in the North Sea.

"We are working to make sure that the improvement in production will be significant, ideally around 10 per cent or more of the original oil in place in the laboratory," explains Amalia Yunita Halim, who adds that the work in the laboratory is associated with a degree of experimental uncertainty. Therefore, the results cannot be translated directly to the North Sea.

Challenges along the way

It has taken a lot of patience to improve the method, which the researchers are expecting to describe in scientific journals. The challenges have included:

- selecting representative core samples, so that comparable tests can be carried out in both the CT scanner and in similar setups without CT scanning
- analysing and using water with the same composition of salts as is found in the oil reservoirs in order to have the right reservoir conditions in the laboratory
- working with a medical scanner that gets hot during the process and thus affects the test so that data had to be 'cleaned' afterwards
- developing a method for working without contrast agent, which is normal with CT scans. The usual contrast agents bind to the chalk and produce poor results
- developing methods for synchronizing the images from the scanner (i.e. combining several images to produce a single image) and filtering them in a resolution that provides true quantitative information.

The development work also demanded considerable innovation along the way. For example, Anders Nymark Christensen found out that, by drilling millimetre-wide holes in the core samples, he could use the holes to synchronize the images.

At the end of 2016, the status is that the method has been validated. Among other things, this is evident from the fact that the saturations from the image analyses from the CT scans are consistent with the mass balance.

"In other words, we now know what we inject, we know what happens inside the core sample, and we know what comes out. This means that we're ready to start testing different EOR methods," says Anders Nymark Christensen, and the two researchers agree that the really interesting part of the work can now begin:

"Our work only becomes really interesting once we find an EOR method which can actually lead to greater oil recovery in the Danish section of the North Sea," says Amalia Yunita Halim.

Alternative methods for water flooding experiments

At the end of 2016, researchers at the Geological Survey of Denmark and Greenland (GEUS) started a series of 'Ekofisk Base Case experiments', with the aim of investigating alternative methods for water flooding under reservoir conditions in the laboratory. In such experiments, oil recovery in the North Sea is simulated under conditions which are as close to reality as possible. One of the challenges today is that the process takes three to four months for each chalk core plug. Can it be done faster?

GEUS will examine this by comparing the usual porous plate technique for saturating core plugs using water with the vapour saturation method.

"Theoretically, the porous plate technique is the most correct for simulating what happens in the reservoir, but the evaporation saturation method is much easier and quicker to use. So, if we can validate that it can be used without any disadvantages, it will be preferable," says Dan Olsen, senior researcher and head of the GEUS Core Laboratory.

GEUS is also examining whether you can use 'dead crude oil' — i.e. oil which is degassed — instead of 'live crude oil', which contains the naturally occurring gases, without impacting the quality of the measurements of the oil recovery. It is faster, easier and cheaper to work with degassed oil.

In addition, GEUS is examining:

- what difference there is in the results depending on whether core plugs are used which are fractured or not. The study may be able to improve the computer modelling of flow in fractured oil reservoirs.
- whether the core plugs can be reused in experiments without it affecting the quality of the results. It would be an advantage if they could be reused, as it is expensive and difficult to obtain core plugs from oil reservoirs in the North Sea.

The Ekofisk Base Case experiments are expected to be completed by mid-2018.

DEMO MODEL AWF2

Improved oil recovery in the deeper part of the Tor formation

The demo model seeks to identify possibilities for increasing the recovery of oil in the deeper part of the Tor formation in the Halfdan field. Logging of observation and monitoring wells along with 4D seismic recordings have shown an uneven vertical sweep mainly efficient in the upper parts. To improve the sweep efficiency in the lower part of the reservoir, research is being conducted into radial jet drilling technology for establishing smaller radial wellbores from the existing horizontal wells. The research focuses on modelling of radial wellbores and induced fractures as well as on the downhole tools needed to operate in the long horizontal section of the existing wells.

DHRTC's hypothesis

Recovery of hydrocarbons from the Tor formation can be increased by providing access to the deeper sections from the existing wells and improve the vertical sweep efficiency. This can be achieved using radial jet drilling or alternative methods that may further be combined with methods for enhancing the induced fractures in the formation.

DHRTC research

To achieve the objective of improving recovery in the deeper part of the Tor formation, DHRTC is conducting research into, for example:

- Modelling of stability and efficiency of jetted wellbores
- Modelling and simulation of induced fractures
- Laboratory testing of the effect on mechanical properties from jetting
- Preliminary study on development of composite coiled tubing
- Simulations for assessing financial viability of solution

New and promising method increases the sweep area in existing wells

DHRTC sheds light on the potential of using the radial jet drilling method to boost oil recovery from the existing horizontal wells in the North Sea.

The oil-bearing chalk strata in the North Sea are highly porous. This means there are a lot of cavities with space for oil. Nevertheless, the chalk is characterized by low permeability, so it is not easy for liquids such as water and oil to move. Commonly, the chalk reservoirs are flooded by water to produce more oil. Under such recovery method, the fluids move through a relatively limited area around the injection and production wells.

The oil industry has successfully developed a technology whereby the wells cover as large an area as possible. This is achieved by drilling horizontall wells along the chalk strata, which are then stimulated with fractures or acid to improve wells' injectivity and productivity. Even using such smart methods, may result in unswept oil-bearing areas - an unexploited potential for recovering more oil - in the reservoirs. A known drilling technology can bring these areas within reach; radial jet drilling (see graphic). DHRTC is working to adapt the method to the conditions in the North Sea, particularly focusing on the deep part of the Tor formation. The work involves everything from research in drilling technology and the development of numerical models to developing the actual technology in cooperation with industry.

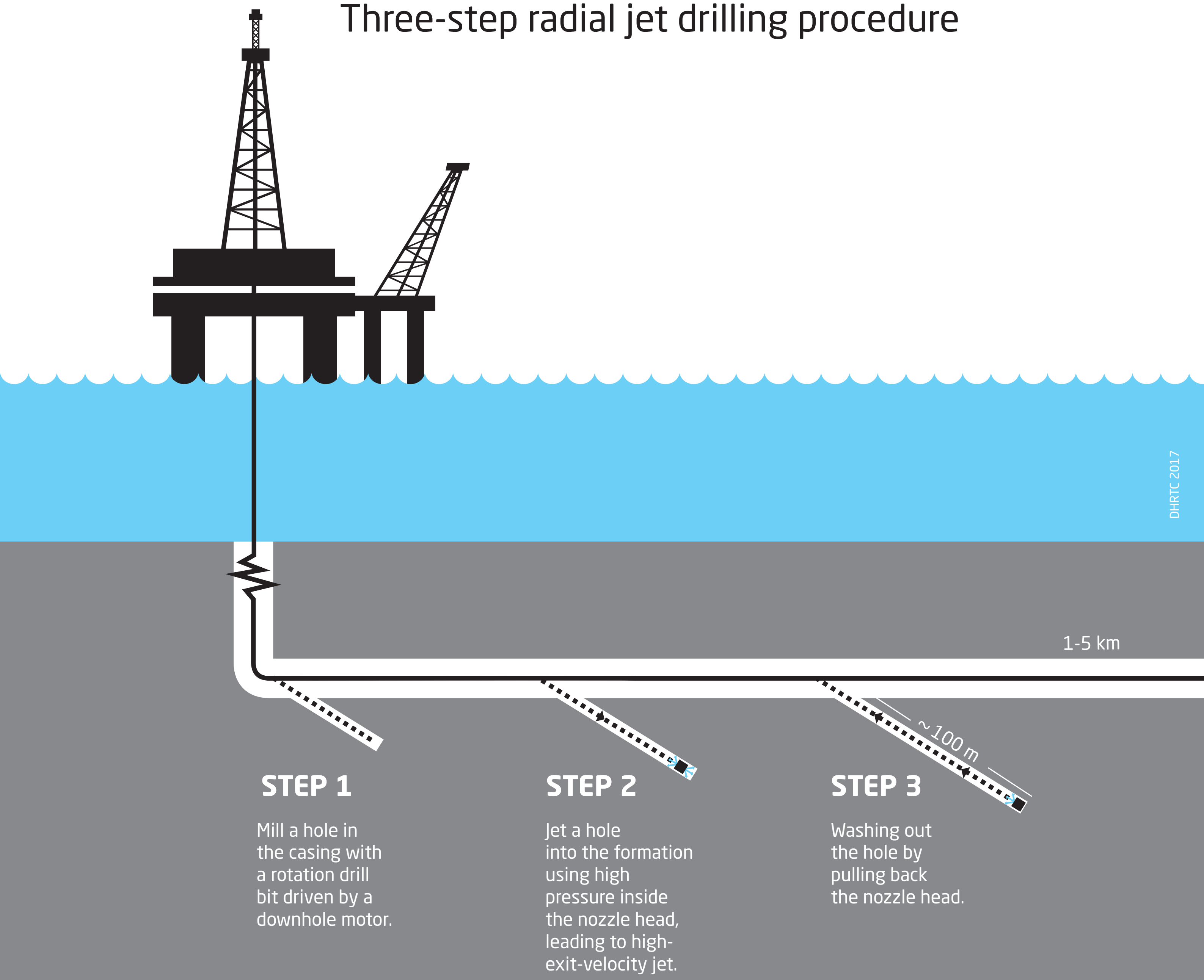
"Radial jet drilling is a relatively mature technology in the oil industry, which has been applied in vertical and inclined wells. So far, it has not been used in the North Sea's horizontal wells," says Senior Researcher Hamid Nick at DHRCT.

The research team

Postdoc Saeed Salimzadeh from DHRCT is part of the research team developing computer models that simulate radial jet drilling in the North Sea's chalk strata. The purpose is to enable the oil industry to plan profitable, new branching of existing wells in the North Sea. The numerical models will be used, for example, to calculate possible improvements of the injection processes and productivity, and indicate the expected 'durability' of the laterals which are drilled from the horizontal wells using jets of water.

In some situations, the new bores may collapse and become blocked. Thus, laboratory tests of the method are conducted to evaluate the stability of the laterals in chalk. The tests are performed by PhD student Maiya Medetbekova and supervised by Helle Foged Christensen. Helle is laboratory manager at Geo, a firm of consulting engineers with subsurface expertise. The research group is also part of a large European Horizon 2020 project with 10 partners, SURE (Novel Productivity Enhancement Concept for a Sustainable Utilization of a Geothermal Resource). In the SURE project, universities and industry are working together to learn more about radial jet drilling for improving energy mining.

Three-step radial jet drilling procedure



Radial Jet Drilling

Radial Jet Drilling is a cost efficient technique that uses a high-pressure water jet to drill numerous radial laterals in one or multiple layers from the main wellbore. The diameter of radials varies between 1 to 2 inches, and their extension can reach up to 100 m. This technique has several advantages over the traditional stimulation method of hydraulic fracturing:

i) this technique does not require large volumes of water;

ii) it is fast as it has the ability to drill up to 8 laterals in two days opposed to a typical four weeks per well as for hydraulic fracturing;

iii) induces minimized damage in the near wellbore area, which is an advantage for production

iv) due to its extended penetration, laterals can reach beyond the damaged area of the well-bore; and more importantly,

The radial jet drilling research team: Postdoc Saeed Salimzadeh, DHRTC, PhD student Maiya Medetbekova, DHRTC, Senior Researcher Hamid Nick, DHRTC, Helle Foged Christensen, Laboratory Managerat Geo. Photo: Mikael Schlosser

SURE runs until 2020, and has three main objectives:

- demonstrating maximum improvement in reservoirs by using radial jet drilling
- clarifying the technological sustainability—including the durability of the wells
- identifying the environmental consequences—compared with other methods for increasing the recovery of heat or oil.

High expectations for the method

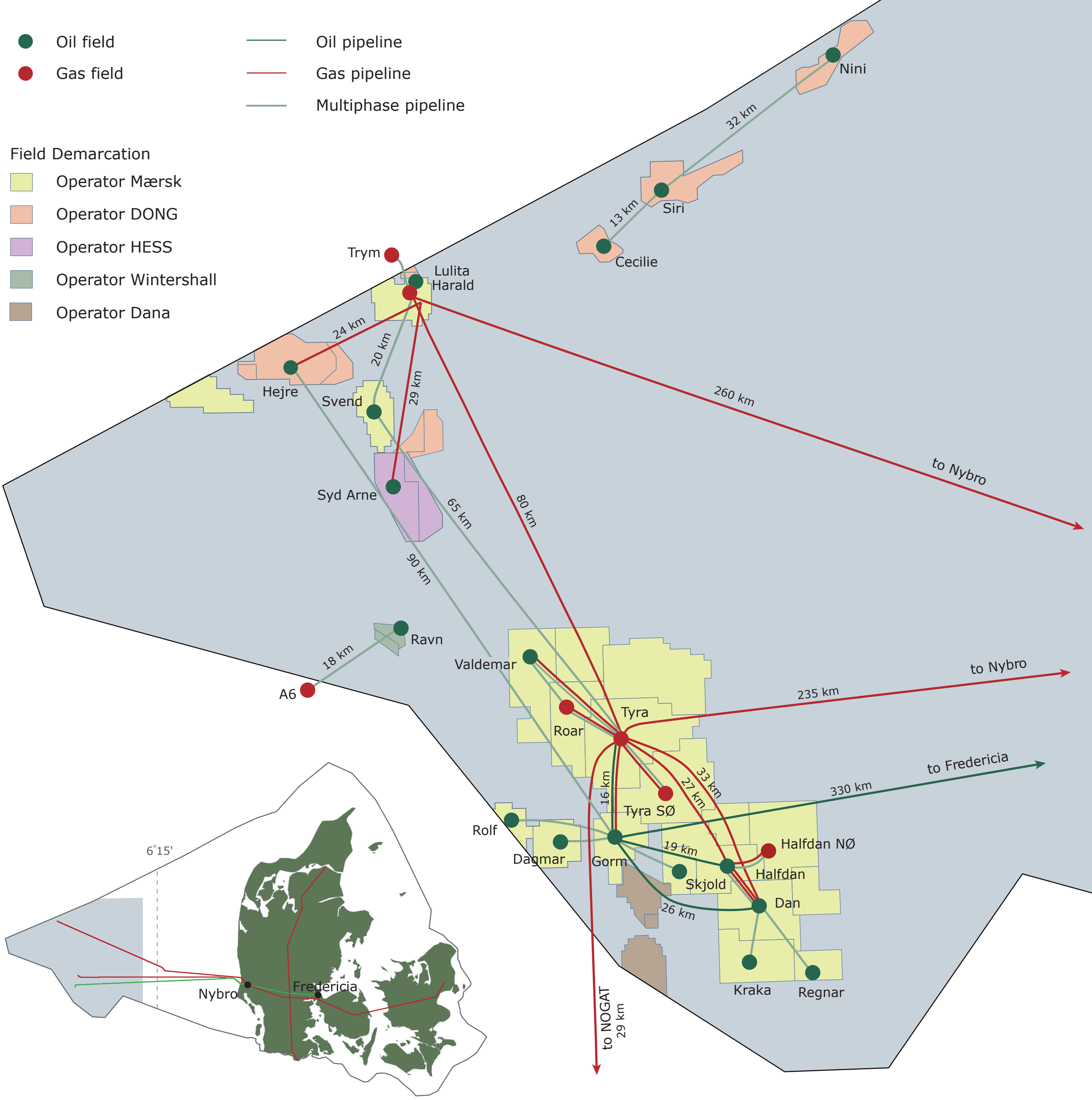
"In the North Sea, we expect radial jet drilling to offer significant benefits compared to other methods of well stimulations, such as hydraulic or acid fracturing in which water and acids are used to induce fractures along the borehole," says Hamid Nick. "Radial jet drilling has, among others, the advantage of using much smaller volumes of water. To water jet a 100-meter length lateral from a well, only 2-5 cubic metres of water is required, and it may not even be necessary to use chemicals, which is much more environmentally-friendly."

DHRTC's work with radial jet drilling began in early 2016. Now, the method is being developed all the way from the laboratory to the field scale in the North Sea. Along the way, testing will be carried out in quarries, in shallow wells and, finally, in the 2–3 km deep reservoirs. The ambition is that the method will be in use in the North Sea in 2019.

Production plants in the North Sea

All of Denmark's producing fields are located in the North Sea and shown in the figure together with the most important pipelines.

Altogether, there are 19 fields which are or have been in production. And recoveries from these fields are handled by three operators: DONG E&P, Hess Denmark ApS and Maersk Oil and Gas. The Hejre and Ravn fields are under establishment but not yet in production. Source: Danish Energy Agency, 2015



Increased oil recovery through a shift on the cost side

Cost Transformation

How can you activate the implicit knowledge which has been generated in recent decades in order to fundamentally change the costs level and thus extend the commercial operation of the Danish platforms in the North Sea? This is the key question which DHRTC's research programme Cost Transformation (CTR) seeks to answer.

Running an oil plant is incredibly complex and involves vast volumes of data each day that people look at and base their decision-making on. This is true all the way from the reservoir and until the oil and gas have been transported to shore in a sufficiently high quality. To make it possible to handle such large volumes of data, the data are filtered based on an implicit understanding of which information is important. This is not necessarily the optimum solution.

To maintain commercial operations for longer periods of time, a change is needed so that large volumes of data which already exist can be processed more efficiently, so that everyone involved is able to make decisions that are more well-founded and relevant.

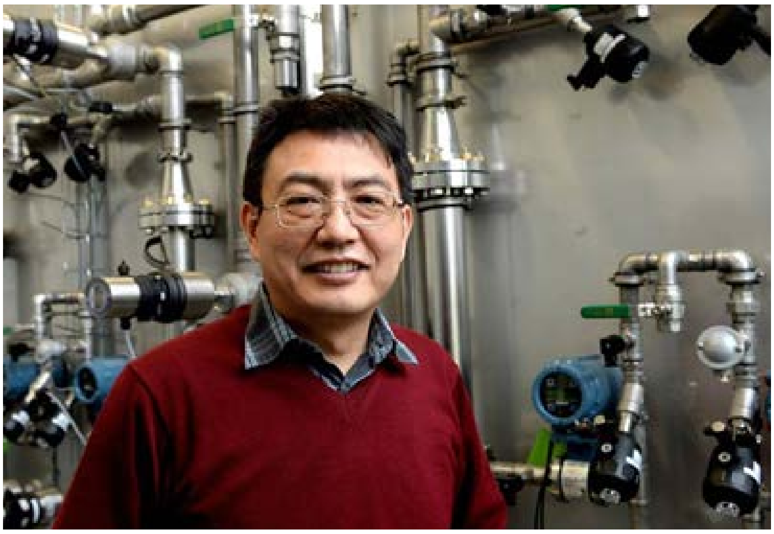
The research conducted in the Cost Transformation programme focuses on three areas:

- Optimization of water injection and systems for treating the water injected and produced, based on an understanding of the data. By improving the systems, it will be possible to increase daily oil production
- Extending the commercially viable operational phase by reducing maintenance costs and investing in improvements to the production facilities. The extra production years will increase the total oil recovery factor
- Extending the structural life span of the platforms and their ability to withstand extreme wave loads so that plant operations are ensured until 2042

Photo: Maersk

Upgraded water treatment can prevent bottlenecks in oil recovery

The more difficult it becomes to recover oil in the North Sea, the more water will be required for the process. The plants that inject water into the wells and clean the production water of oil and chemical residues need to be upgraded.



"With the new technology, we can increase production regularity and get down to zero per cent discharges," says Zhenyu Yang, Associate Professor at the Department of Energy Technology at Aalborg University in Esbjerg. Photo: André Thorup, JydskeVestkysten

In order to maintain the pressure in an oil reservoir and to stimulate production, increasing volumes of water need to be injected into the oil-bearing, geological strata so that the displaced oil can be 'swept' to the adjacent production wells.

"Today, producing a single barrel of oil often comes along about three barrels of water. And the produced water does not bring profits. When the hydrocarbon is brought up and separated into gas, oil, and water, the production water which contains both oil residues and chemicals needs to be cleaned before it is discharged into the sea or before it can be re-injected. Therefore, it makes sense to research how we can optimize this process," says Zhenyu Yang, Associate Professor at the Department of Energy Technology at Aalborg University in Esbjerg.

At the beginning of 2016, researchers from Aalborg University started working with researchers from DHRTC. The project is part of the 'Water Management' programme under DHRTC, and may well contribute to increased oil and gas production, but also potentially improve the quality of the cleaned water which is discharged to the sea or re-injected into the wells.

The issue is not urgent as such, but certainly very relevant on the platforms in the North Sea.

"You need to remember that the installations for injecting and treating the water from production date back to the 1970s. Oil recovery today requires more and more water, and this means that the water treatment plants have to be able to keep pace. By increasing the amount of water which is injected, and the amount of water which is treated, you can also increase the amount of oil which is produced," says Zhenyu Yang.

The project is aiming for significant production improvements. The researchers are suggesting three solution models, and all the solutions are being tested on Aalborg University's pilot plant in Esbjerg.

The first solution is the easiest and the cheapest and does not require significant investments. It involves modifying and improving the automation system software which, for example, controls the opening of valves and the flow and injection of water.

It is a so-called 'software retrofit' solution that improves the productivity of the existing water treatment plant by adjusting the control systems while leaving the mechanical design intact. This means minimal downtime during implementation.

"By developing a software-based system that regulates the individual systems, we are eliminating the weaknesses in the individual systems and getting them to work together as one big dynamic system. In this way, you better utilize the oil that is recovered, which increases productivity while significantly reducing the oil content in the return water," he says.

The second solution combines software and hardware improvements. The solution requires limited investments in hardware — for example the installation of new sensors and new pumps, which, together with new software, will improve the overall performance of the entire plant. This solution will improve productivity more than the first proposal.

The third solution is more far-reaching.

"The ultimate aim of our research is a technological breakthrough where we will use the very latest technologies in the control systems and ceramic membrane filtration. By means of advanced modelling and an intelligent control strategy, this solution will ensure a high level of regularity and availability in production as well as the zero emission of hydrocarbons from the production water. It calls for development and major investments, but on the other hand it can lead to higher regularity in operations and improved protection of the environment in the oil and gas industry without compromising production capacity or production costs," says Zhenyu Yang. The project is being developed in close collaboration with DTU Electrical Engineering.

The oil companies have to submit daily reports on the presence of various substances in the cleaned production water which is discharged to the sea. At the moment, the requirement is that the water must not contain more than 0.003 per cent (30 ppm) oil residue.

"With the new technology, we can increase production regularity and get down to zero per cent discharges of oil residue," he says.

Water Management project

The project is a collaboration between DHRTC, the Department of Energy Technology, Esbjerg under Aalborg University, DTU Electrical Engineering, DTU Compute, and Maersk Oil.

The project focuses on, among other things, the advanced control and optimization of produced water – including relevant facilities and processes with the following goals:

- Significant increase in production. Reduced environmental impact: reducing the discharge of hydrocarbons from 30 milligrams per litre of water to zero
- Improved productivity: relative to the production volume equivalent to from 2 to 10 per cent
- Project start: 1 February 2016
- Project end: 31 January 2019

The research group suggests three solution models:

Software-retrofit solution: This solution is based on the existing production facilities and processes, where you develop and use advanced control and automation software to achieve the above objectives.

Combined software and hardware-retrofit solution: This solution will seek to achieve the objectives with limited improvements to facilities and processing by means of new hardware combined with new, advanced control and automation software.

Technological breakthrough solution: With the help of an intelligent control strategy and advanced modelling based on Multilevel Flow Modelling based on advanced membrane filtration, this solution will ensure a high level of regularity and availability in production, as well as zero emissions of hydrocarbons from the production water.

DEMO MODEL CTR1

Big data analyses to increase water injection

In order to maintain the significant increase in capacity which has been obtained by optimizing the water injection systems(-WI systems) and also the produced water treatment systems (PWT systems) at the oil production plants Dan and Halfdan, the demo model focuses on developing models that describe the plants. To prepare the models which can help operators optimize plant operations, big data computer methods are used based on data from the past and present.

DHRTC's hypothesis

- It is possible to prevent a reduction in the availability of water injection/produced water treatment over time by using big data analyses
- Reasons for downtime can be identified

DHRTC research

To achieve the objective of improving water injection and produced water treatment systems by means of big data, DHRTC is conducting research into, for example:

- The development of specific cause-consequence models (MFM) to ensure online causal assessment and decision-making support
- The documentation of validation and verification in connection with Aalborg University Esbjerg (AAU-E) PWT pilot plant
- 'Classic' big data exercise for Dan's water injection/PWT packs
- The development of a 'surrogate model' in the MFM method
- The development of relational software between MFM, FMECA, HAZOP and P&ID 'languages'

Tomorrow's wellhead platforms offer best value for money

When building a new unmanned wellhead platform, you can choose to do what you have always done, but if, out of economic necessity, you decide on a simple model with only the most necessary functions, is this really the most expedient choice, also in the long term? A DHRTC team om researchers from DTU Mechanical Engineering have sketched their design for the cost-effective platform of the future.

We are talking billions of Danish kroners when establishing a single, unmanned wellhead platform and connecting it to the overall production system. The platform alone costs about DKK 400 million. Consequently, a lot of money could be saved by taking a different approach if you have to build a new one.

This was the background for the LEAN Wellhead Platforms research project, where researchers from DHRTC and DTU Mechanical Engineering tested the hypothesis that it makes financial sense to combine modular architecture and LEAN thinking when building new platforms. There were a lot of synergies between the project and an ongoing Maersk Oil project.

In other words: Is it possible to develop a prototype of a so-called wellhead platform — an unmanned platform — which, in addition to being the most financially favourable over a 10-year period, is also modular, so that it can easily be expanded to meet future needs and coupled to existing production platforms which are operated by Maersk Oil in the Danish section of the North Sea?

"Our research shows that, compared to 'business as usual', it is possible to realize potential savings of 20–30 per cent on the upper part of a platform which is only equipped with the bare minimum. However, if you do not choose the cheapest individual solutions throughout, but take into

An unmanned wellhead platform is a platform with no permanent crew. Photo: Maersk

account maintenance costs and the consequences of all the various choices you make along the way, you can achieve even greater economies," says postdoc Poul Martin Ravn from DTU the research team.

The researchers from the centre concluded the project in Summer 2016, when the report was submitted to Maersk Oil. The scientific articles from the project will soon be published.

New mindset behind research project

The team of researchers challenged the conventional approach and used the ideas behind product architectures to identify the most cost-effective platform.

This involves taking an overall look at the platform as if it was composed of building blocks, where you analyse the different physical elements, and for each one you develop different

An unmanned wellhead platform:

- is a platform with no permanent crew
- has space for 6-10 wellbores
- in the North Sea is based on a so-called STAR (Slim Tripod Adapted for Rig Installation) platform

The collaboration project:

- was a project between DHRTC, DTU Mechanical Engineering and Maersk Oil
- was carried out in the period December 2015 – June 2016
- compared 15 existing wellhead platforms
- focused on the use of modular architecture to identify core functions and modules and thereby achieve economies
- clarified the costs and consequences of operational, functional, and physical design choices

DEMO MODEL CTR2

Restructuring operating and maintenance costs

The demo model identifies various possibilities for reducing maintenance costs and for investing in production improvements at the Gorm field's production plant. A decries in operation cost offers a postponement of the economic cut-off date resulting in an increased recovery., and thus the field can be used more optimally and for a longer period of time.

DHRTC's hypothesis

- The considerable uncertainty surrounding the assumptions on which the desired cost reduction are based can be handled by means of operational control and modular technical investigations
- Further cost improvements can be achieved by inhibiting corrosion externally and by designing new lean wellhead platforms
- The concept for planning maintenance, procedures, and satellite design can be optimized

Expected key deliverables

- Cost reduction by means of novel maintenance planning
- New concept for wellhead platforms
- Advanced repair options with cement
- Tool for planning well intervention
- Test and validation of deposit and corrosion-inhibiting techniques

During the project, the researchers from DHRTC were in constant contact with Maersk Oil project managers and engineers to get qualified feedback from specialists on their analyses. Photo: Poul Martin Ravn

options. Then, you look at the mutual consequences of the building blocks in context, and combine them in various scenarios.

"This gives you a clear overview of how the different choices affect capital and operational expenditure, i.e. the costs associated with constructing and operating an oil rig," says Poul Martin Ravn.

Many critical choices

After a thorough analysis of four wellhead platforms in the North Sea, the researchers were able — together with experts from Maersk Oil — to define seven different core modules which involve several critical choices.

One question, for example, is how to clean the pipes that run between the platforms.

"Here, you can choose between two solutions. Either you can clean the pipe in one direction, where you have to send a crew out to the otherwise unmanned platform, or you can design a looped pipe, which makes it possible to send the cleaning device — a so-called pig — forwards and backwards. The latter solution is more expensive and more complicated to establish, but it means that the pipes can be cleaned without physically visiting the wellhead platform," he says.

With the former solution, you have to have crew on the wellhead platform to dispatch the pig.

"This requires both manpower and a boat with a crane, because the pig weighs more than what the personnel are allowed to lift. In this case, the most cost-effective solution in the long term is the most expensive to establish, where you avoid having to send crew out to the wellhead platform. From an occupational health and safety perspective, it is also preferable," says the researcher.

Cheapest solution not necessarily the best

An unmanned platform usually has between six and 10 wellbores going down into the subsoil, depending on how the oil and gas are distributed. It must be possible to shut off production from the wells — for example in connection with maintenance.

"The question is: Must it be possible to close the valves separately for each well, or is it better to have a combined closing mechanism which closes all the wells at once? Here, it turns out that it is cheaper to build a combined closing mechanism, but in the long term it is far from the most cost-effective solution because then it is not possible to repair or maintain an individual borehole without shutting down production completely," says Poul Martin Ravn.

Experiences from real life

During the project, the researchers from DHRTC were in constant contact with Maersk project managers and engineers to get qualified feedback from specialists on their analyses.

"At our monthly meetings, the researchers presented their findings. Sometimes we had to adjust the assumptions for their conclusions. But other times they certainly had some points that challenged our 'business as usual' approach," says Jakob Knudsen, a project manager with Maersk Oil.

For Maersk Oil, working with a university on a development project is a completely new thing.

"It's never really possible to know whether we would have arrived at the same conclusions without DTU, but DHRTC has done a fantastic job and helped us along the way. We were certainly able to really get to the bottom because the researchers had the resources and the methods to shed light on the various options in much more detail than we usually do," explains Jakob Knudsen.

Need for more knowledge about the load from extreme waves

Unusually high and very irregular waves occur more frequently in the North Sea than previously assumed. But how often, and how do they impact the platforms? DHRTC's research project Extreme waves is seeking answers to these questions.

Platforms in the North Sea are designed to withstand being knocked about a bit. By severe storms and strong currents — even by waves so huge that statistically they should only occur once every 10,000 years. But can the statistics be relied on? And how are the platforms impacted by the extreme waves?

"Today, we don't know enough about extreme waves. We don't know how frequently they occur, we don't know why they occur, and we don't know enough about the impact of the waves for us to define the degree of uncertainty in relation to the design of offshore structures," says Professor Christos Thomas Georgakis from the Department of Engineering at Aarhus University.

Extreme waves are rare, but they happen more frequently than previously assumed. 1 January 1995 is an important date in this context.

It was a stormy day — perhaps a little rougher than usual. Around the Norwegian platform Draupner in the North Sea, the sea was so rough that the waves measured 12 metres from crest to trough. Suddenly, a huge rogue wave measuring 26 metres appeared out of nowhere. The wave was not only unusual because of its height. It was also the first time that such an extreme wave had ever been accurately detected with measuring equipment. Until then, only anecdotal evidence from seafarers existed about

Objective of the 'Extreme waves' project

- DHRTC will create an improved load model that can be used by the industry to determine more precisely the loads which offshore structures are subjected to by extreme waves. The purpose is to substantiate the safety of existing structures and to create a basis for more optimum designs in future.
- DHRTC is seeking to develop a technology that can measure the wave impact indirectly and in real time by means of sensors. By measuring the response from the platform – in other words how much it moves – it will be possible to determine the load from the waves.
- DHRTC will further develop the analyses of the data coming from the LIDAR systems – a combination of laser and radar that registers wave frequency and size. Here, DHRTC can contribute with the improved collection, processing, and comparison of data that can contribute to modelling waves with existing software.

DEMO MODEL CTR3

Extend life of platforms to secure infrastructure

With a view to ensuring the operation of existing offshore production platforms beyond 2042, the aim of the demonstration model is to demonstrate the ability of permanent structures to withstand impacts from extreme waves. Attempts will be made to solve this challenge through a combination of improved monitoring, greater understanding of the physics and frequency of extreme waves, as well as advanced methods for uncertainty handling and risk assessment.

To the extent that a prolonged life span can thereby be supported, this opens up for the possibility that existing production facilities can act as nodal points in future tie-in solutions.

DHRTC's hypothesis

Through an improved understanding of structural response and extreme waves, the research hypothesis is to supplement DUC's AWARE project with a view to reducing the level of uncertainty in the risk analysis, and to thereby enable decisions to be made concerning extended life spans, structural reinforcements, operational initiatives, etc.

Expected key deliverables

- Statistical description of the actual strain.
- Wave statistics and monitoring data
- Structural monitoring data
- Validation of structural calculation models
- Load model for and statistical description of extreme, breaking waves
- Risk modelling

The project 'Extreme waves' aims to develop an improved model for the loads which offshore structures are exposed to. Photo: Maersk Oil

these sudden huge waves.

In 2012, a Maersk Oil employee photographed a high breaking wave on the Tyra platform in the Danish section of the North Sea.

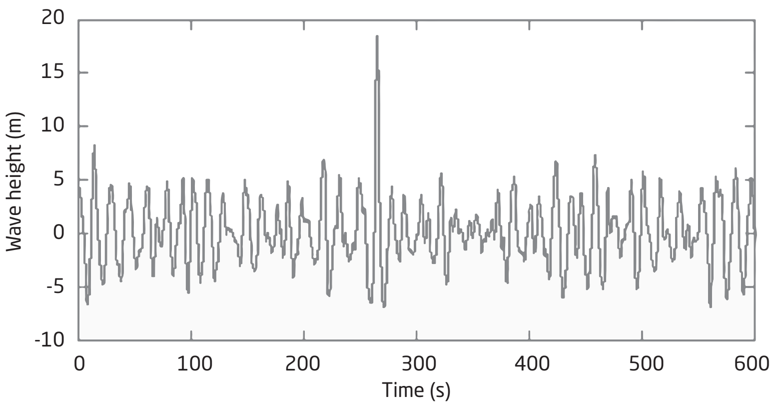
"For such a dramatic wave type to occur out in the open sea was completely unexpected. And it raised the question: Were the platforms designed to withstand these extreme waves?" asks Professor Christos Thomas Georgakis from the Department of Engineering at Aarhus University.

A potential threat

The episodes resulted in a number of further investigations.

"Maersk Oil launched a major project to map the impacts from breaking waves. The focus was mainly on the platforms in the Tyra field which had sunk with time, so that the distance from the surface of the sea to the platforms was reduced. The overall conclusion was that the waves could potentially pose a threat, and that more research in the area was needed," he says.

That was the reason for establishing the research project 'Extreme waves', which is a joint project by DHRTC and Aarhus University with the partners DTU Mechanical Engineering, DTU Wind, DHI, and Maersk Oil.



The 'Draupner wave' — a single, monster wave that was measured on the Norwegian platform of the same name on New Year's Day in 1995 — confirmed the existence of extreme waves, which until then had been regarded as almost mythical. Source: DMI

Test facilities at sea

The project aims to develop an improved model for the loads which offshore structures are exposed to, to develop a technology that can measure wave impacts, and, finally, to improve the collection, processing, and comparison of data.

"Initially, we are focusing on evaluating the importance of a number of fundamental assumptions. However, it is our hope that the project will grow, and that we get to understand the impact of waves better, among other things by establishing an inshore experimental centre," says Christos Thomas Georgakis.

Most of the existing knowledge about breaking waves and their impact comes from experimental wave pools around the world. The problem is that the natural spatial and environmental conditions cannot be replicated exactly.

"A typical wave pool is 50 cm deep and has artificially created waves. When simulating sea depths of 45 metres, the scale is 1:90. However, we know for a fact that there are scaling effects, and a test centre on a scale of 1:10 would be very useful for being able to assess the errors from these scaling effects," he says.

Whether the test centre will be established and where it might be situated is still unknown. However, Christos Thomas Georgakis is in no doubt about the potential benefits.

"If we build a test centre with a water depth of 5–6 metres, we can measure the interaction between waves and structures on a scale that is not 1:90, but 1:8 or 1:9 instead. And for every extreme wave that we register in the North Sea, we can probably register 10,000 corresponding waves at a depth of 5 metres close to the shore. This will give us much more accurate data about the impact of extreme waves," he says.

Increased recovery from the Tuxen formation

Is it possible to achieve a stable production of oil from the deepest chalk stratum in the North Sea, the Tuxen formation? This is the focus of DHRTC's latest research programme – Tight Reservoir Development (TRD).

Today, in certain oil fields the oil industry recovers oil from the deep chalk stratum, the Tuxen formation, which was formed more than 100 million years ago. The Tuxen chalk is less permeable than the chalk in the Ekofisk and Tor formations higher up, and it presents a challenge that the production varies so much from well to well. There are relatively large quantities of oil in the Tuxen formation at locations where the industry already has infrastructure in place. However, there is a need to clarify how best to develop production, and to clarify whether new investments in equipment would be worthwhile. At the end of 2016, DHRTC decided to initiate the research programme Tight Reservoir Development, which focuses on finding out more about the deep chalk stratum. The programme will be described in more detail in demo models in 2017. From the outset, it is clear that it is necessary to conduct research into the core disciplines of geology and geophysics, as knowledge about the formation is still incomplete.

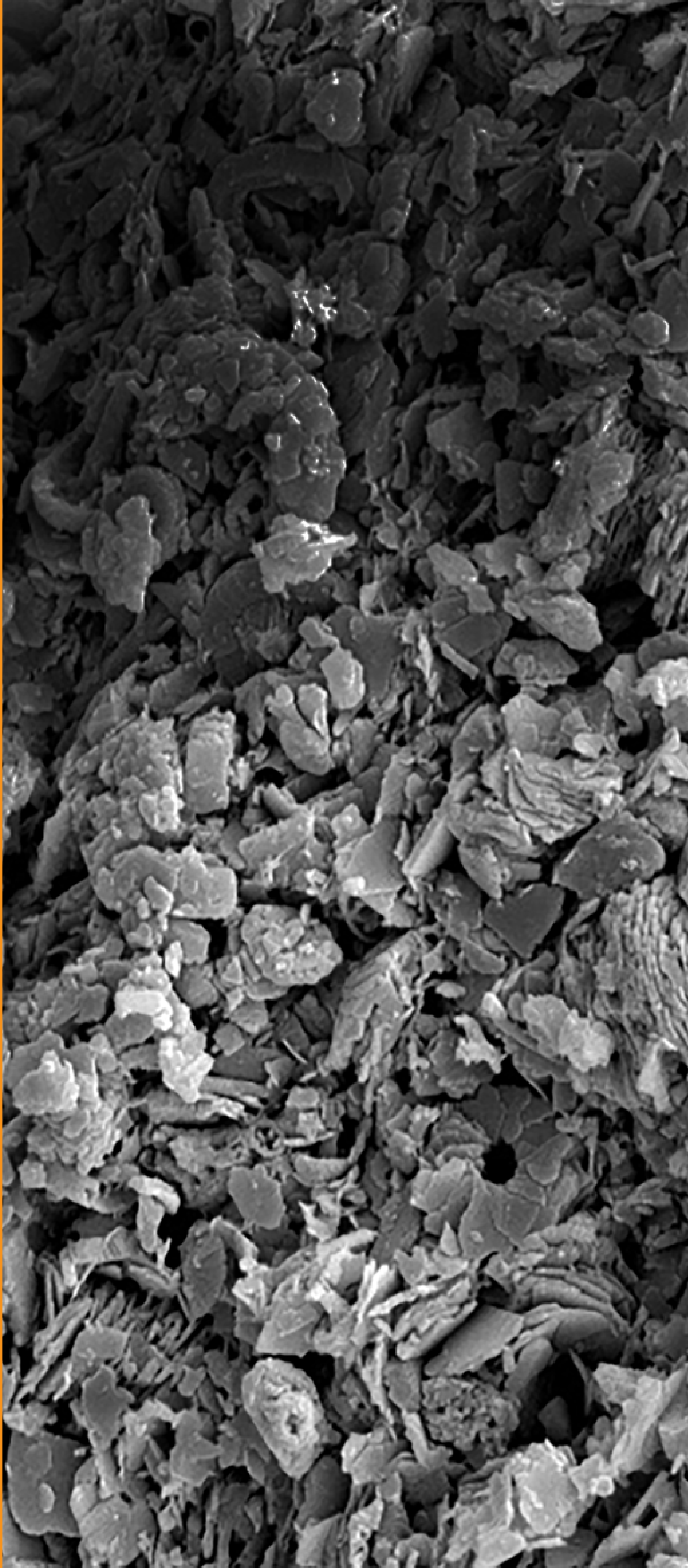


Photo: Finn Jakobsen et al. 2003, GEUS

Presentations and discussions in plenary sessions. Photo: Mikal Schlosser

First DHRTC conference on the potentials in the North Sea

In 2016, DHRTC held its first conference on the potentials for Danish oil and gas in the North Sea.

In November, about 200 representatives from the business communities, authorities and the university world met for the two-day DHRTC Technology Conference 2016 in Helsingør north of Copenhagen. Focus of the conference: How can we work together to develop models for solving the challenges that oil and gas extraction faces in the coming years in the Danish part of the North Sea?

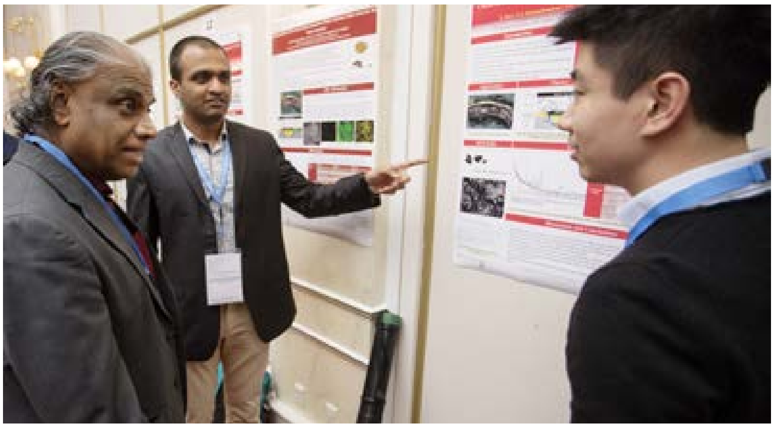
"During its first years of existence, the Centre has attracted many highly qualified people, and we are now ready to discuss what we have learned," said Bo Cerup-Simonsen, Director of the Danish Hydrocarbon Research and Technology Centre. "DHRTC aims to generate new knowledge, innovation, and new solutions. This requires us to create a good collaborative model which can make large businesses and universities work together. Instead of working with a classic organisation, we need to cooperate in networks in new ways."

At the conference, researchers and businesses from abroad contributed with knowledge and input. Among the attendants were representatives from Norway, the UK, the Netherlands, and Mexico.

On the first day of the conference, 'co-creation' was in focus with presentations and discussions about how the business community and universities can cooperate in the best possible way despite their different success criteria. The second day of the conference was dedicated to scientific presentations and discussions about the academic challenges.

On the DHRTC website, you can see the conference programme and read the abstracts. Next year's conference will be held on the 14th and 15th of November at Comwell Kolding.

Debates and network during breaks. Photo Mikael Schlosser



Scientific discussions at the poster session. Photo: Mikal Schlosser

Co-creation - Highlights from the panel discussion

Henrik Tirsgaard, Head of Technology & Innovation at Maersk Oil:
"For DUC and Maersk, this cooperation means that we have a great opportunity to evolve towards a more open system where we share our challenges in exchange for a greater and more focussed engagement from the universities. It is no small challenge to get industry and the five universities to work effectively together. For it to succeed there has to be an underlying belief that it will work and that we can trust each other's motives. We must focus less on optimising own interests and more on the common interest in ensuring that this cooperation bears fruit and DHRTC can evolve over many years to come. DHRTC has found a good way of organizing the work with the focus of the demo models on specific challenges and solutions. All the demo models are attractive for industry, and the individual work packages under each model are interesting for the researchers."

Colette Cohen, CEO at the Oil & Gas Technology Centre, UK:
"It is important for us to create the right culture for innovation to succeed. So far, our industry has mainly evolved out of necessity. We tend not to introduce new technologies because they are interesting, exciting or transformational. We do so when we have an urgent need. There are many solutions that could have been implemented earlier, but when the oil price was high our focus was elsewhere. Now, in this period of lower oil prices, technology is essential to improving efficiency and we must work together to find the best solutions."

Ole Ringdal, CEO at the International Research Institute of Stavanger (IRIS):
"The industry needs application-oriented solutions, patents, and commercialization. The researchers are focusing on citations, quality evaluations, and peer reviews. You need to ensure that academia is able to live up to high academic standards. You cannot force a professor to cooperate on something he or she does not find interesting."

Peter Van Giessel, Venture Principal, Shell Technology Ventures:
"At Shell, we spend a billion dollars a year on research and innovation. We are working together to attract talents, to bring new ideas on board, and to obtain knowledge that can help us decide what we should focus on in our development. However, we don't believe there is a natural flow from the universities to industry in the form of useful solutions. In addition, the process is too long, often decades."

Publications 2016

Frank Niessen. **In Situ Techniques for the Investigation of the Kinetics of Austenitization of Supermartensitic Stainless Steel.** Materials Science Forum

Muhammad Imran, Hamidreza M. Nick, Ruud J. Schotting. **Application of infrared thermography for temperature distributions in fluid-saturated porous media**. Arabian Journal of Geosciences

Kevin Bisdom, Giovanni Bertotti and Hamidreza M. Nick. **A geometrically based method for predicting stress-induced fracture aperture and flow in discrete fracture networks**. AAPG Bulletin

Kevin Bisdom, Giovanni Bertotti and Hamidreza M. Nick. **The impact of different aperture distribution models and critical stress criteria on equivalent permeability in fractured rocks**. Journal of Geophysical Research: Solid Earth

Kevin Bisdom, Giovanni Bertotti and Hamidreza M. Nick. **The impact of in-situ stress and outcrop-based fracture geometry on hydraulic aperture and upscaled permeability in fractured reservoirs**. Tectonophysics

K.L. Jepsen, L. Hansen, C. Mai and Z. Yang. **Challenges of membrane filtration for produced water treatment in offshore oil & gas production**. IEEE Explore Database

Skafte, Anders ; Aenlle, Manuel L. ; Brincker, Rune. **A general procedure for estimating dynamic displacements using strain measurements and operational modal analysis**. Smart Materials and Structures

S. Pedersen, K. Stampe, S. L. Pedersen, P. Durdevic and Z. Yang. **Experimental Study of Stable Surfaces for Anti-Slug Control in Multi-phase Flow**. International Journal of Automation and Computing, Vol. 13, No.1, 2016, pp.81-88

Saeed Salimzadeh, Adriana Paluszny, Robert W. Zimmerman. **Three-dimensional poroelastic effects during hydraulic fracturing in permeable rocks**. International Journal of Solids and Structures

R.A. Crooijmansa, C.J.L. Willemsa, H.M. Nicka and D.F. Bruhn. **The influence of facies heterogeneity on the doublet performance in low-enthalpy geothermal sedimentary reservoirs**. Geothermics

Conferences

K. Bisdom, G. Bertotti and H.M. Nick. **The Great Unknown in Fractured Reservoirs - The Impact of Three Models for Aperture and Flow in Fractured Reservoirs**. 78th EAGE Conference and Exhibition 2016

Z. Yang, P. Durdevic and S. Pedersen. **Optimization of Offshore De-oiling Hydrocyclone Performance: Plant-wide Control and Real-time OiW Measurement**. Proc. of 2016 NEL Produced Water Annual Workshop, Aberdeen, 07-08.06.2016

Z. Yang, S. Pedersen, P. Durdevic, C. Mai, L. Hansen, K.L. Jepsen, A. Aillos and A. Andreasen. **Plant-wide Control Strategy for Improving Produced Water Treatment**. Proceedings of 2016 International Field Exploration and Development Conference (IFEDC), Beijing, 11-12.08.2016, peer-reviewed

Saeed Salimzadeh, Hamid M Nick, Adriana Paluszny and David Bruhn. **Towards numerical modelling of THMC coupled processes in fractured geothermal reservoirs**. European Geothermal Congress 2016

K.L. Jepsen, L. Hansen, C. Mai and Z. Yang. **Challenges of membrane filtration for produced water treatment in offshore oil & gas production**. OCEAN'16 MTS/IEEE Monterey, 19-23.09.2016

A. Ameri, H.M. Nick, N. Ilangovan and A. Peksa. **A Comparative Study on the Performance of Acid Systems for High Temperature Matrix Stimulation**. Abu Dhabi International Petroleum Exhibition & Conference, 7-10 November, Abu Dhabi, UAE

Denis Kirchhübel. **Representing Operational Modes for situation awareness**. 13th European Workshop on Advanced Control and Diagnosis 17 - 18 November 2016, Lille, France

P. Durdevic, S. Pedersen, and Z. Yang. **Challenges in Modelling and Control of Offshore De-oiling Hydrocyclone Systems**. Presented at 13th European Workshop on Advanced Control and Diagnosis (ACD 2016), 17-16. 11.2016, Lille France.

Master and Bachelor thesis 2016

Hugo Amor. **Predictive workover and maintenance model for the Dan field.** MSc

Kasper Torbensen. **Predictive workover & maintenance model.** MSc

Marcin Wlodarczyk. **Comparing different well completions on the performance of water flooding in chalk reservoirs.** MSc

Michael K. Hansen. **Proactive Well Workover Maintenance Model.** BSc

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Photo: Joachim Rode

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This list does not include Sprint employees.

Photo: Joachim Rode

DHRTC Projects 2016

Project title
AWF.1 - Development of Ekofisk
Recovery processes on Core Scale
Equipment for Water-Flooding Experiments at GEUS Core Laboratory
Investigating the Potential for Miniaturized Core Flooding Experiments
Waterbased EOR - Flood
Reservior Simulation
Waterbased EOR- Simulation
Waterbased EOR- Simulation
Reservior Fluid Characterisation
Oil Chemistry at the Kraka oil field
Waterbased EOR - Reservoir Fluid Characterization
Waterbased EOR - Reservoir Fluid Characterization
Waterbased EOR - Flood
Waterbased EOR - Flood
Outcrop analogue studies of Chalk - Integrated goelogy, geophysics and geostatics
Outcrop analog studies of chalk
Rock mechanics and Fluid saturation study
Rock mechanics and fluid saturation study
Improved Geomodel with deterministic fracture representation
Improved geo-model with deterministic fracture representation
Improved geo-model
Saturation model review
Natural fracture detection and modelling
Seismic Geomorphology and Reservoir Characteristics of Chalk Fields
Seismic Geomorphology and Reservoir Characteristics of Chalk Fields
Waterbased EOR-Reservoir Fluid Char /Seismic geomorphology and reservoir characteristics of chalk fields
Fasttrack - Optimized Image Analysis of CT Scanning of Core Floods
Chemical flooding: Dimethyl ether
Chemical flooding: Dimethyl ether
Chemical flooding: Dimethyl ether
Chemical flooding: Dimethyl ether
Oil composition & surface studies with IR facilities for EOR
Oil composition & surface studies with IR facilities for EOR
Wettability and pore structure understanding for increased injectivity
Wettability and pore structure understanding for increased injectivity
AWF.2 - Improved Sweep in Deep
Modelling Injector Related Hydraulic Fracturing
Modelling Injector Related Hydraulic Fracturing
Radial Jet Drilling
EU SURE Project - Radial Jet Drilling
Composite coiled tubing
Composite coiled tubing - Feasibility study

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Project title
CTR.1 - Increase Water Injection Availability
Multilevel modelling (MFM) of design, decision and plant processes
Water management
Combining functional modeling and reasoning with on-line event analytics
Big Data methods for identifying cause and effects for down time
Big data management for identifying cause and effect of downtime/ Water management
CTR.2 - Transformation of Asset Cost
Lean well head Platforms
Lean well head Platforms
Lean well head platforms
Self-healing cement
Self-healing cement
Cost reduction by 4D maintenance planning
Identification of cost savings potential for maintenance across Gorm/Dan, Tyra & Halfdan
Scale & Corrosion
High performance stainless steel by interstitial alloying
Supermartensitic Stainless Steels (SMSS) for Oil and Gas Applications
Improved Cement Remediation and Evaluation
Improved Cement Remediation and Evaluation
CTR.3 - Extend Life of Potential Hub Structures
Structural Intergrity & Monitoring
Structural integrity and Monitoring
Feasibility study on the use discrete element modelling on offshore installations
Extreme Waves
Extreme waves – Direct and indirect load estimation
Risk Modelling
Value of information and Risk based inspection Planning
Risk informed decision support projects

Additionally, a great number of smaller sprint projects have been funded throughout 2016.

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