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CT scanning of core flooding experiments: Quantitative analysis of saturation without dopant

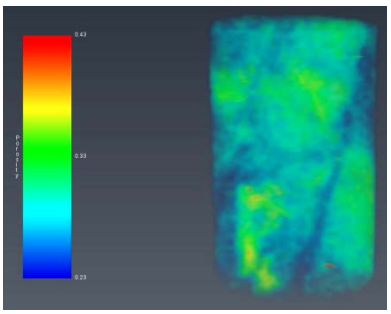
CT-scanning of core flooding experiments allows us to investigate how different EOR agents work, and lets us quantify saturation in possible unswept areas. We present an automatic method for analysis of CT scans of two-phase core flooding experiments without the use of dopants.

Anders Nymark Christensen, EOR group, DHRTC, Amalia Yunita Halim, EOR group, DHRTC

Core flooding experiments are used for testing enhanced oil recovery strategies (EOR) on a laboratory scale. In a typical core flooding experiment, the core plug contains oil, water and potential EOR agents. It is of importance to understand the multiphase flow of these liquid inside the porous rock formation. The combination of X-ray CT scanning and image analysis has been used to study multiphase flow in porous media for a few decades. However, in low permeable reservoir rocks, the interpretation of multiphase flow experiments is still a challenge. Previous experiments have been conducted with the aid of dopants in oil or water phase, but this has been showed to be infeasible in chalk, as the dopants bind to the chalk.

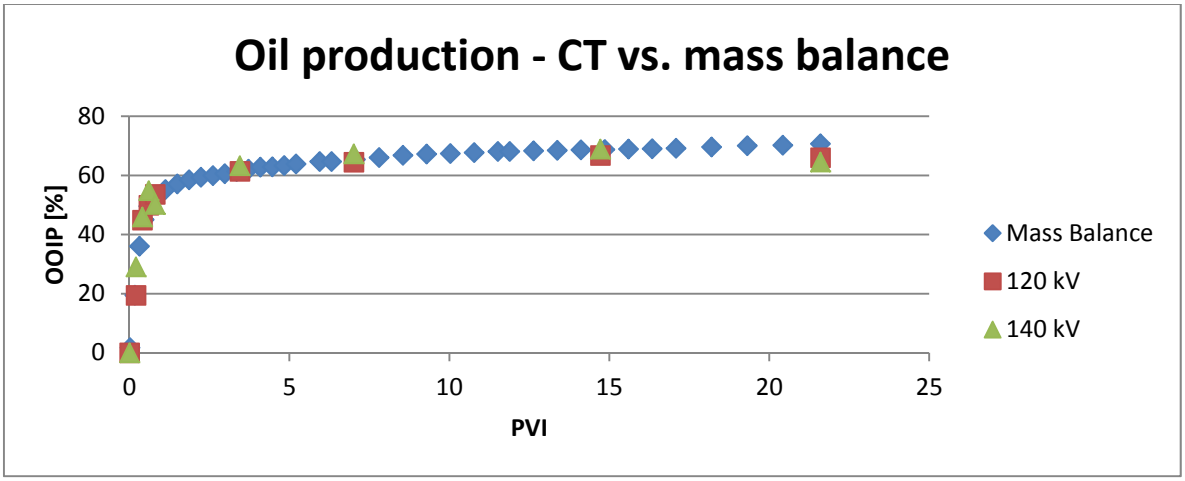
A CT scanner works by taking conventional X-ray images from all around the object. These images can then be mathematically transformed to yield a 3D image of the object. By calibrating the images and precisely aligning consecutive scans, we can get porosity and saturation images in 3D.

Methodology and software has been made for automatic extraction of porosity and saturation maps. We strive to extend the methodology to three-phase flow systems, where the quantification is more challenging.



To the left we see an example of a 3D porosity map estimated using the CT scanner. The dark lines are low porosity planes not immediately apparent on the surface of the plug

Below we see the oil production from a core flooding calculated in two ways: from mass balance and from the CT scans. There is a very good agreement between the two types of measurements



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Mathematical modelling of advanced water flooding in the North Sea chalk reservoirs: a closer look

Summary

Ali Akbar Eftekhari, Hamid M. Nick, Erling Stenby, DHRTC, Technical University of Denmark

Several pore and core scale experimental investigations have shown that the injection of brine with an ionic composition different from the reservoir brine can effectively increase the recovery of oil in the chalk and carbonate reservoirs. Upscaling these successful experiments to the pilot and field scales requires a thorough understanding of the underlying physical mechanisms. So far, the suggested mathematical models are either case-specific, i.e., include one or more tuning-parameters, or only cover a fraction of the physicochemical interactions. In this work, the first problem is addressed by using a large database for tuning the model parameters, and the second problem is addressed by including more physical mechanism in the mathematical model. Furthermore, an automatic procedure is implemented for finding a correlation between the surface properties of chalk and oil, and the measured rate of oil recovery and residual oil saturation.

Petroleum analysis by non-target chromatographic methods

Mette Kristensen and Jan H. Christensen, University of Copenhagen, Department of Plant and Environmental Sciences, Section of Environmental Chemistry and Physics, Analytical Chemistry group.

Non-target analysis has several advantages over traditional target analysis and allows us to identify relevant compounds and look at “all compounds at once”. Sample preparation should therefore be non-selective or with complementary selectivity so the entire range of compound properties are covered by few analytical platforms. Non-target analysis has been extensively used in the area of petroleomics and some of the methods include GC/LC-MS, GCxGC-MS, LCxLC-MS, LC-SFC-qTOFMS and IM-MS.

All petroleum samples are unique and the chemical composition depends on origin, reservoir conditions, formation temperatures and many other factors. As for humans, each petroleum sample therefore has a unique fingerprint, the *chemical fingerprint*, which can be characterized by advanced non-targeted chromatographic methods. The chemical fingerprint can e.g. be used for source identification, sample characterization and comparison between petroleum samples. When performing non-targeted chemical fingerprinting, a huge amount of data is generated and multivariate data analysis is required to cope with the resulting data sets.

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Long Core Water-flooding Experiments on Chalk at Reservoir Conditions

Dan Olsen, Senior petrophysicist, GEUS

Summary

Experiments with forced-flow water-flooding of non-fractured long core samples at reservoir conditions are compared. Ekofisk formation chalk results in much higher Sorw than Tor formation chalk. Inhomogeneous chalk results in significantly higher Sorw than homogeneous chalk. A densitometer in the flow-line just after the outlet of the core sample provides valuable information of the progress of the flooding experiments.

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Life-cycle oil production optimization using proper risk-measures and closed-loop reservoir management

Summary

John Bagterp Jørgensen, Andrea Capolei, Lasse Hjuler Christiansen, Tobias K.S. Ritschel, Steen Hørsholt, Technical University of Denmark

We discuss work flows for long term production optimization of oil reservoirs. In particular, we present a closed-loop reservoir management procedure and discuss appropriate risk measures for the production optimization. Closed-loop reservoir management involves an ensemble of prediction models, a state and parameter estimator (history matching, Ensemble Kalman Filter), and an optimizer for the optimal control problem. This procedure is also known as nonlinear model predictive control (NMPC). We discuss each of these components in closed-loop reservoir management and present results based on simulation examples. Finally, we point to connections to real fields in the North Sea and required development in software tools to support systematic closed-loop reservoir management.

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Thermodynamic modeling of Smartwater

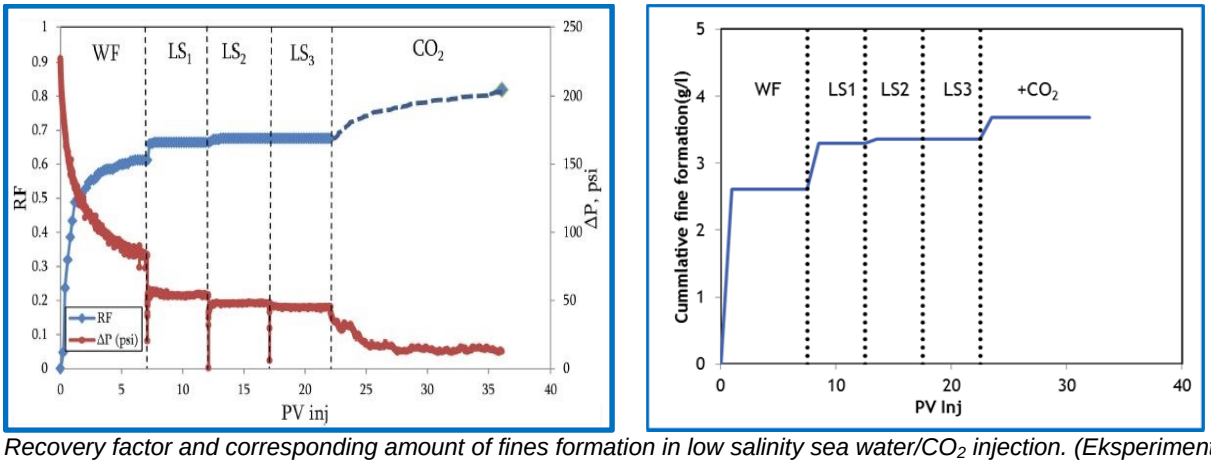
Summary

Kaj Thomsen, Associate Professor, kth@kt.dtu.dk, Department of Chemical and Biochemical Engineering, DTU.

”Smartwater” is one of the terms used for describing brines with modified salt composition used for enhanced oil recovery. The salt composition is changed in order to achieve the best possible effect when it is injected. There is not a single explanation of the mechanisms responsible for promoting the recovery of oil. The most common explanation is the wettability alteration mechanism. By changing the pore walls of the reservoir rock from oil wet or mixed-wet to a more water wet condition, oil is mobilized and can flow through the pore. Sulfate ions adsorb on reservoir walls and replace carboxylic groups that were previously attached to the pore walls. Calcium and magnesium ions reduce the electrical potential differences between oil droplets and pore walls by being attached to the sulfate ions. Sulfate, calcium, and magnesium ions play an important role in this mechanism and are often referred to as “potential determining ions”.

When brine is injected, it changes temperature and pressure. It is also mixed with formation water. At the same time, the brine interacts with the reservoir walls. Density functional theory (DFT) was applied for investigating the brine – rock interaction. One of the main results of the DFT calculations is that magnesium ions get an energy advantage by replacing calcium ions on the rock surface. This confirms the observed tendency of magnesium ion deficiency in the effluent brines from core flooding experiments.

The temperature and pressure change, the mixing with formation water, and the brine – rock interaction affect the solubility of the salts that can be formed by the brines. Scale calculation software includes all these effects. By analyzing brine conditions using scale calculation software, it can be shown that supersaturation and possibly the formation of nuclei or fines play an important role in laboratory core flooding experiments and perhaps also in Smartwater EOR.



Recovery factor and corresponding amount of fines formation in low salinity sea water/CO_2 injection. (Eksperimental data from Teklu et al. 2014, 91°C, Thermodynamic calculations by Nipun Garg, MSc thesis DTU, 2016). Injection of sea water followed by increasingly diluted seawater. During LS3 injection, the concentrations are insufficient to form fines. CO_2 injection dissolves carbonate, the increased Ca^{2+} concentration causes $CaSO_4$ (anhydrite) to precipitate/form fines.

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Finite strain evolution of the Kraka field

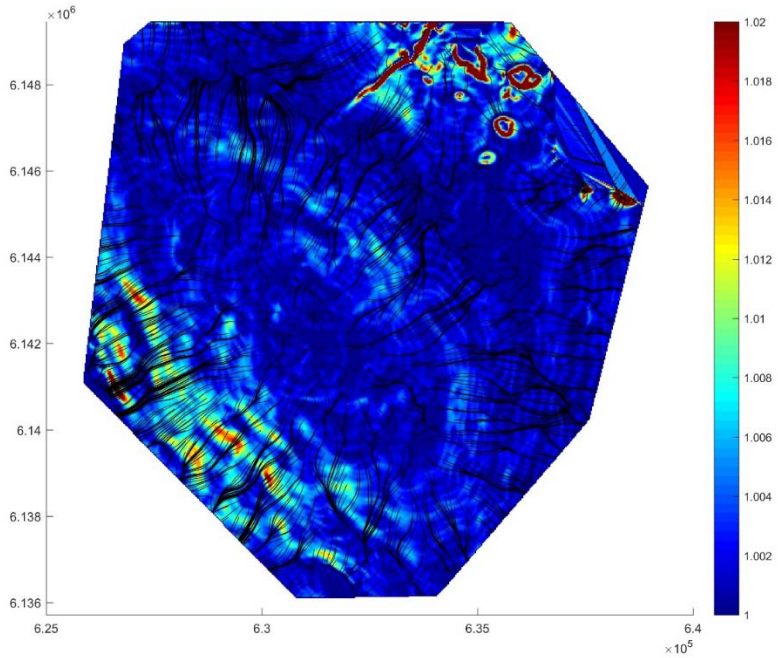
Kenni Dinesen Petersen, Postdoc, Department of Geoscience, Aarhus University

Ole Rønø Clausen, Department of Geoscience, Aarhus University

Katrine Juul Andresen, Department of Geoscience, Aarhus University

Michael Welch, The Danish Hydrocarbon Research and Technology Centre, DTU

In many of the North Sea chalk reservoirs, the development of fractures exerts an important control on hydraulic properties. Seismic imaging is capable of resolving macroscale (e.g. 10-100 m) fractures, but the fractal nature of fracture generation implies that they occur at smaller scales as well. Here we attempt to predict the distribution of fractures in the Kraka field by inferring the deformation history of the reservoir. We do this by mapping layers above the chalk using 3D seismics and apply a technique called 'backstripping' where the burial history is inferred from the thickness of the layers above the chalk. By calculating spatial gradients of the burial history, we estimate an associated deformation history. The inferred deformation history appears to be consistent with observations from well data.



Modeled strain of Top Chalk. Colors indicate the magnitude of the maximal principal stretch, and 1.00 (dark blue) corresponds to 0% strain and 1.02 (dark red) corresponds to >2% strain. Black lines indicate the direction of the maximal principal stretch.

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Imaging the Subsurface: reservoir characterization of Kraka from BHIs

Summary

Tala Maria Aabø, Research Assistant, Center for Oil and Gas - DTU

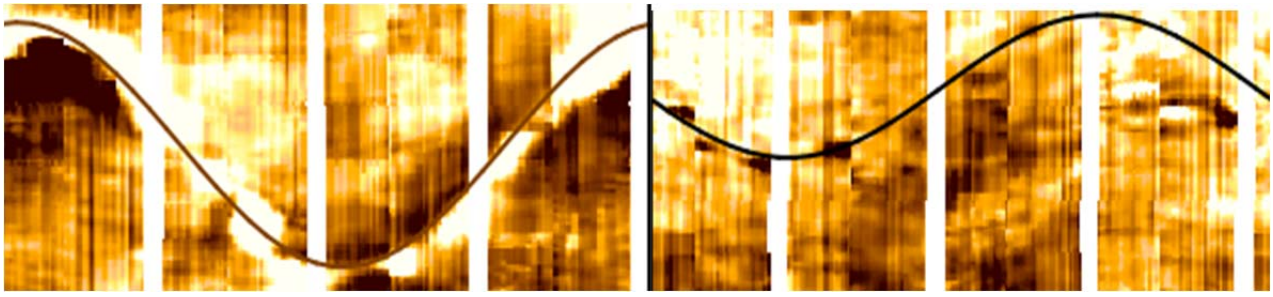
The Kraka Field is an anticlinal structure induced by halokinesis. A thin saturated oil column in the Ekofisk Formation is produced through natural depletion. Although the matrix permeability of the chalk is <1mD, it is heavily fractured which gives an effective permeability approximately 20 times greater. The current recovery factor is however only 12%. An increased understanding of fractures and reservoir characteristics in Kraka will allow for improved EOR activities (e.g. gas injection, water injection etc.) and should therefore increase the recovery factor.

Borehole image (BHI) and core analyses are part of an effort to build a mechanically based discrete fracture network (DFN) model of the field. Micro-resistivity images from FMS, FMI and MWD tools are available in one vertical well and ten horizontal/deviated wells, four of which include core data. Cored sections are used to verify BHI interpretations.

The lithology varies between pure chalk and marly chalk, with varying amounts of flint layers and nodules. There is localized staining which is cyclic and often associated with the flint. In such cases, a sharp boundary between high resistivity and very high resistivity responses are observed in BHIs. Although image quality is varying, the flint is easily identifiable on BHIs across the field. This allows for one-to-one correlation between images and cores, and is useful in determining depth-shifts.

Open extensional fractures and calcite-cemented fractures, which occur in swarms, are detectable in borehole images. However, the exact fracture sinusoids are in many instances less than obvious due to poor image quality. All fracture picks are therefore assigned a confidence number based on signal strength. Stylolites are also commonly observed in core but are harder to identify on borehole images.

BHI picks, core fracture logs and sedimentological analyses are combined in an interdisciplinary approach to a) compare observations from the datasets, and b) check for possible relationships between datasets. These results are linked to 3D seismic interpretations and fracture maps based on seismic attributes.



Examples of a high confidence resistive fracture (left) and a low confidence conductive fracture (right) in vertical well A-10P. The wellbore has been surveyed by an FMI tool, and represents the best image quality available from Kraka.

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Overview of geomechanical properties from Dan and neighbouring fields

Leonardo T.P. Meireles[†], Michael Welch[††] and Ida L. Fabricius[†]

[†] Technical University of Denmark, Dept. Civ. Eng., 2800 Kongens Lyngby, Denmark.

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This work presents an analysis of the results of geomechanical tests carried out by geotechnical contractors on reservoir core samples from the Dan, Halfdan and Kraka fields. Elastic (Figure 1) and strength parameters were calculated and are presented against assumed controlling parameters, such as porosity, stratigraphic unit and saturating fluid used during the testing.

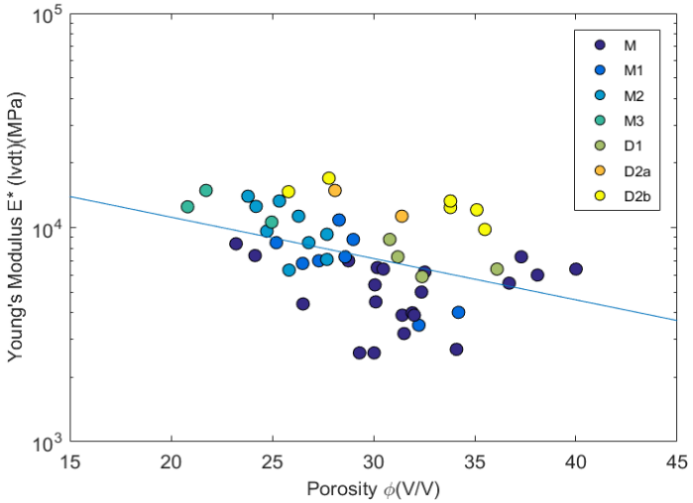

Figure 1- Young's Modulus vs porosity for different stratigraphic units

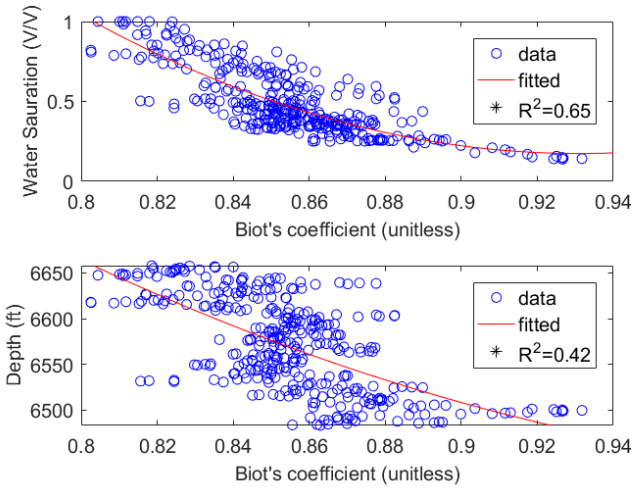

Figure 2 – Cementation in the M-10X, Maastrichtian unit: Correlation with Sw (a) vs correlation with Depth (b).

While the restricted number of geomechanical tests run with samples saturated with water/brine makes it difficult to evaluate the impact of saturating fluid on the stiffness of the chalk (water weakening) a more detailed analysis of the data revealed a less obvious relationship between the native water saturation of the samples and stiffness/strength. A preliminary assessment of the petrophysical logs on these wells suggests a strong correlation between initial reservoir water saturation and Biot's coefficient (a measure of cementation) assessed from sonic logs (Figure 2a).

Although the assessment of currently available data allow us to loosely correlate rock stiffness and strength to petrophysical attributes such as porosity, a causal, theoretical relationship cannot be established between those. In order to thoroughly understand the basic mechanisms governing stiffness and strength of chalk, additional petrophysical and petrographical analysis are proposed to investigate frictional mechanisms as described by Andreassen and Fabricius (2010), contact cementation and Biot's coefficient as described by Fabricius (2014), as well as electrostatic mechanisms as described by Nermoen et al. (2015).

Fabricius, I. L. (2014). Burial stress and elastic strain of carbonate rocks. *Geophysical Prospecting*, *62*(6), 1327–1336.

Nermoen, A. et al. (2015). Extending the effective stress relation to incorporate electrostatic effects; Extending the effective stress relation to incorporate electrostatic effects. *SEG Technical Program Expanded Abstracts*, pp. 3239–3243.

Andreassen, K. ., & Fabricius, I. . (2010). Biot critical frequency applied to description of failure and yield of highly porous chalk with different pore fluids. *Geophysics*, *75*(6), E205. http://doi.org/10.1190/1.3504188.

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3D Modelling of Fracture Deformation, Propagation, and Interaction

Saeed Salimzadeh, Hamid M. Nick, DHRTC, Technical University of Denmark

A framework is proposed to model fracture deformation within a three-dimensional poroelastic medium, subject to mechanical, hydraulic and thermal loading. Fractures are defined as two-dimensional, piecewise-planar surfaces that cut through the three-dimensional poroelastic medium. Flow through fractures is defined by lubrication theory, while flow through permeable matrix is captured using Darcy's law. The two flow fields are coupled to the elastic mechanical model using hydraulic loading within fractures, and effective stress concept within matrix. In non-isothermal conditions, advective-diffusive heat transfer through both fracture (2D) and matrix (3D) is defined. The governing equations are solved numerically using finite element method. Linear and quadratic unstructured mesh is used for discretisation of fracture (triangle) and matrix (tetrahedral). The onset and direction of the fracture propagation is evaluated using three stress intensity factors (KI, KII, KIII), computed for 50 locations (tips) on each fracture front. The model has been implemented using CSMP (Complex Systems Modelling Platform), and validated against numerous published examples. Several problems including hydraulic fracturing, interaction between multiple hydraulic fractures, and fracture's aperture variation during production are simulated.

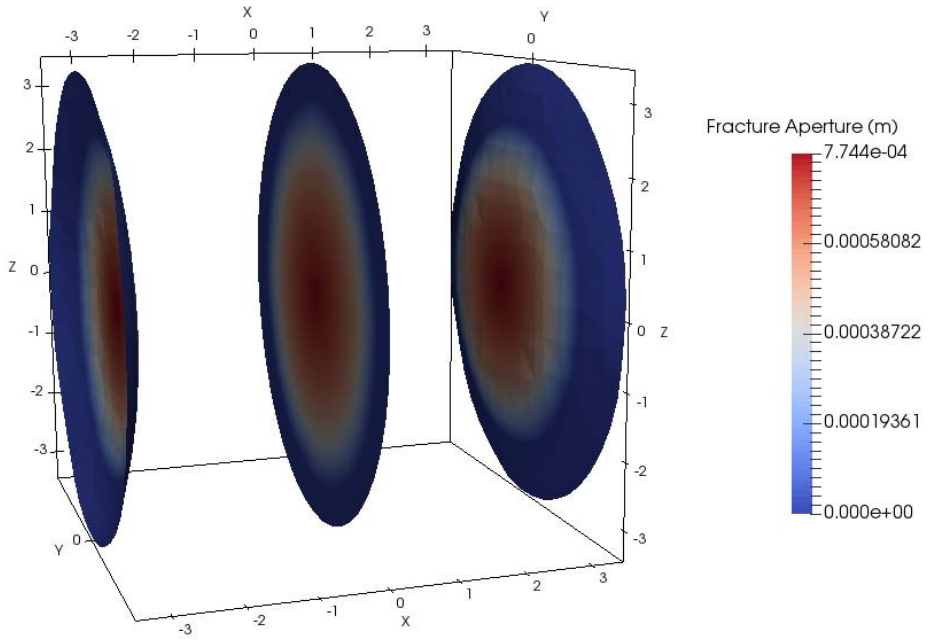

Figure 1. Interaction between three hydraulic fractures, simultaneously created from a single horizontal well

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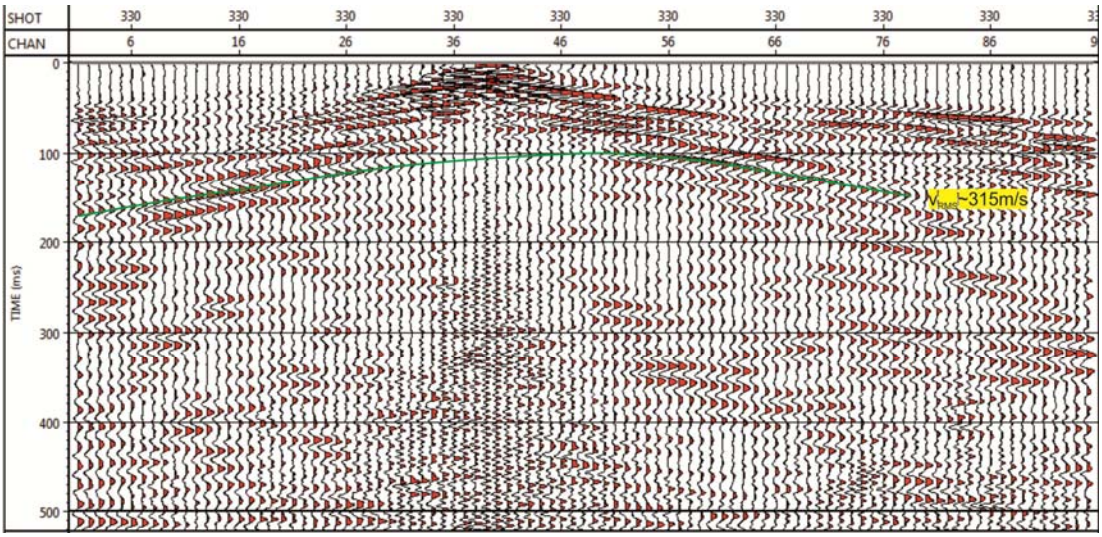
High resolution P- and S-wave reflection seismics linked to log data in chalk reservoir analogues at Stevns, Denmark

Janina Kammann [(1)], Lars Nielsen [(1)], Lars Stemmerik [(2)], Alireza Malehmir [(3)]

IGN, University of Copenhagen, (2) SNM, University of Copenhagen, (3) Department of Earth Sciences, Uppsala University

In this study we present the first results of a seismic survey at a test site close the chalk cliffs in Stevns and the Stevns-1 borehole north of Sigerslev quarry. Two seismic datasets, one with a vertical-component and another one with a horizontal-component source, were obtained from the same location and compared to the Stevns-1 borehole logging data. The 440 m deep Stevns-1 borehole is located a few meters from the seismic profiles and is therefore ideally placed for integration of rock data with the seismic datasets. P-wave seismic data were collected by using an accelerated 45-kg weight drop and a 200 m long land streamer with 3-component broadband digital-based MEMS (micro-electro-mechancial) sensors. The fieldwork in March was part of an international PhD course and the equipment from Uppsala University was used. With this method we were able to image the whole Chalk Group, which is in part analogous to the chalk reservoir rocks in the North Sea, down to the base of chalk at approx. 900 m depth. A first analysis of the vertical component data shows that changes in the P-wave reflectivity within the Chalk Group correlate with changes in gamma ray and lithology in the Stevns-1 borehole implying clay-conent controls on the reflectivity. With the horizontal component survey (the so-clalled SH-SH), we are able to penetrate approx. 100 m with a vertical resolution on a meter scale. The equipment consists of an Elvis S8 seismic shaker source and a 96 m long land streamer (with 96 geophones each 1 m apart), and stands out by delivering high resolution data of the shallow subsurface. This equipment will be used for further chalk reservoir analogue studies in the coming year.



Example shot gather with a reflection marked (green) for guidance (at 330 m distance along the profile) from the SH-seismic data from Stevns Klint – Some basic scaling and filters were applied to the data to reduce ground-roll and improve signal visibility.

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Upper Maastrichtian – Danian silica distribution and reservoir properties, Chalk Group, southern Danish Central Graben

Kasper Høj Blinkenberg[1], Kresten Anderskouv[2], Mattia Tagliavento[1] and Lars Stemmerik[1]

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Silica, its distribution and influence on reservoir properties in the Danish North Sea chalk is relatively poorly documented and subject to continuous debate. Silica is most common in the Danian Ekofisk Formation and occurs as a number of different textures e.g. continuous and discontinuous bands and nodules and finely disseminated particles within the chalk matrix. The variability of fabrics suggests a highly dynamic diagenetic system and thus requires an integrated approach from nano-, microscopic-, core-, well log-, and outcrop scale in order to fully understand the role of silica for reservoir properties in chalk.

Calibrated handheld X-ray fluorescence analyses of plugs from three wells, Sif-1X, Nana-1XP and A-3 have been acquired to investigate the stratigraphic and regional distribution of silica in the uppermost Tor and lowermost Ekofisk formations in the southern Danish Central Graben. The wells were selected to test producing and non-producing structures and longest possible stratigraphic section. Analyses were restricted to plugged intervals to allow direct comparison between analyses and reservoir properties. The data indicate stratigraphic control on the silica distribution across the region with highest values in all three wells in the mid-Danian (Fig.1) In addition, the data show a negative correlation between silica content and reservoir quality in all

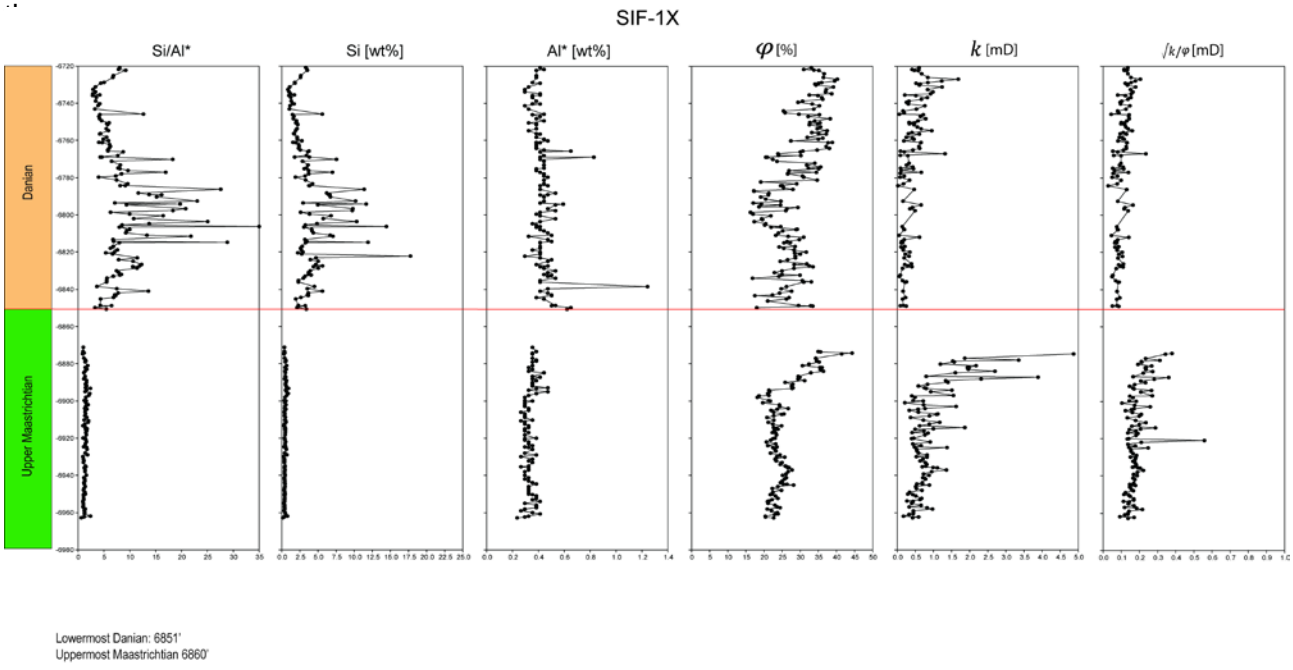


Figure 1: SIF-1X distribution of Si/Al* and reservoir properties in the upper Maastrichtian Tor and Danian Ekofisk chalk. Note the distinct stratigraphic control of Si/Al* and the inverse correlation between Si/Al* and ϕ in the Danian Ekofisk Formation.

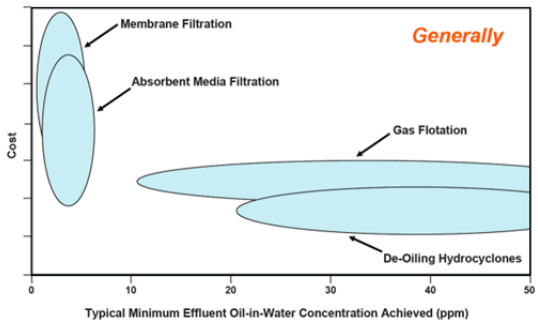
Advanced Control for Produced Water Treatment

Zhenyu Yang, Associate Professor, Dept. of Energy Technology, Aalborg University

Summary

One of the biggest environmental concerns in offshore oil & gas production is the quality of tremendous amounts of Produced Water (PW) discharged into the oceans. Today, in average three barrels of water are produced along with each barrel of oil. According to OSPAR reports, the produced water is the main contributors to the oil discharges from offshore oil and gas activities, for instance, representing 98% of the total amount of oil discharged to the sea in 2006. The current OSPAR limitation of dispersed oil discharge in North Sea is set at 30mg/l (30ppm) as the permitted maximal. When the regulation becomes more stringent, traditional PW treatment technologies will struggle in fulfilling these new requirements. In addition, new methods of enhanced oil recovery make use of chemicals which favor the formation of emulsions characterized by very small and tight dispersed oil droplets. These new situations also challenge the conventional PW treatment technologies, as well as the injection water treatment technologies in case that the PW is re-used for injection purpose.

This presentation will introduce some key investigation and development of innovative PWT technologies, committed by the OG research group at AAU via three research projects – PDPWAC, GreenOil Lab and SWMS, by employing the model-based plant-wide control strategy. This talk consists of (i) introduction of AAU's PWT pilot-plant; (ii) the advanced anti-slug analysis and control by focusing on the upstream well-pipeline-riser systems; (iii) optimization of controlling topside separation processes, which includes both the three-phase separator and de-oiling hydrocyclone facilities; (iv) a brand new *direct efficiency-based PWT control* and Oil-in-Water (OiW) real-time measuring technologies; as well as (v) challenges of ceramic membrane filtration for PWT.



PDPWAC

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Smart Water Management Systems (SWMS)

- *Left figure - the general classification of offshore PWT technologies in terms of performance vs. cost. (Sinker, A., "Produced Water Treatment Using Hydrocyclones – Theory and practical application", 4th Int. Petroleum Environmental Conference, Houston, USA, 5-9 Nov 2007)*
- *Middle figure – logos of three projects: PDPWAC: Plant-wide De-oiling of Produced Water using Advanced Control (IF, 04.2013-12.2016); GreenOil Lab: Green PWT for Offshore OG Production (Det Obelske Familiefond & AAU, 01.2015-09.2016); SWMS: Smart Water management Systems (DHRTC, 02.2016-01.2019)*
- *Right picture - a snapshot of the PWT pilot plant at AAU Offshore Energy Systems Laboratory*

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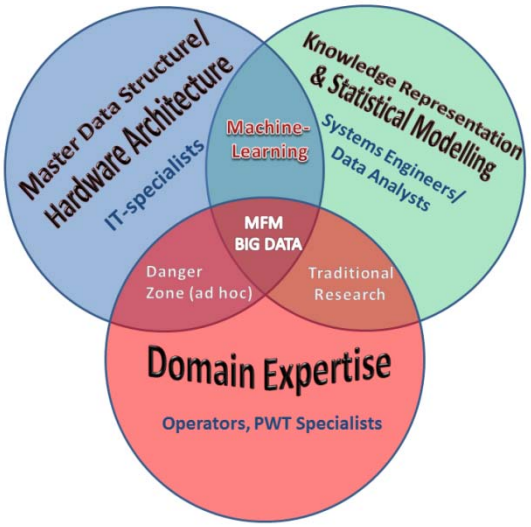
Making Sense of Big Data for Produced Water Treatment

In order to identify, detect, prevent, and respond to production outages it is tempting to explore whether important insight can be obtained by advanced analysis of data from an extended sensor network, such as the one provided by SCADA and other online- measurements – in other words a Big Data solution. Such a solution may also make use of external data feeds such as weather conditions, market demands, or even spot oil price. One could hope that such a solution could avoid the need for analysis by numerous domain experts because today's experts seldom have time to collaborate on monitoring the big picture. In reality this is probably often too optimistic. Instead one should apply domain knowledge to tailor the architecture when designing the data-analytics methodology and possible combine it with other methods and resources.

In the case of Produced Water Treatment we specifically address the problem of reducing the 'human errors' when dealing with alarms. Alarm systems play critical roles in maintaining plant safety and ensuring the process operates within normal operating ranges. In this presentation we list some of the main research challenges in dealing with the fact that many alarm systems suffer from poor performance. We argue how historical data and data-driven methods should be integrated with connectivity-based methods that make use of process knowledge. Process knowledge includes the fact that many process variables are related to each other via mass and energy conservation laws.

Thomas Martini Jørgensen, Senior Researcher, DTU Compute



Fault Management using Multilevel Flow Modelling

Summary

Emil Krabbe Nielsen, PhD student, DTU Elektro

Estimates show that 3-15 % of production loss in the petrochemical industry is due to anomalies, disturbances, shutdowns etc. These anomalies can produce 40.000 different alarms on modern oilrigs. Handling these alarms efficiently is crucial to increase the productivity of complex systems. Automated fault detection and diagnosis has the potential to decrease the loss in productivity, by instantaneously detecting or predicting faults, diagnosing the causes and consequences, and alarming an operator or eventually counteracting and recovering the system autonomously.

In this way the operators' decisions are enforced by intelligent alarm systems, improving the basis and information on which operators take action in order to prevent or recover the system from faults. The system has the potential to detect and diagnose faults based on computational speed in real-time and present the most probable root cause and consequences to the operator – ultimately saving time, money, ensuring a sound and uniform product, safe and unharmed equipment, by reducing system down time and need for maintenance. Additional features could include product and equipment traceability regarding quality and faults, in auto-generated reports.

Multilevel Flow Modeling (MFM) is a methodology from artificial intelligence for functional modeling of industrial processes. The basic idea of MFM is to represent an industrial plant as a system which provides the means required to serve purposes in its environment. MFM has a primary focus on plant goals and functions and provides a methodological way of using those concepts to represent complex and dynamic industrial plants.

MFM has been used for fault diagnosis of nuclear power plants, electric power systems, a combustion engine, valve and cooling systems, an incineration plant, a fuel injection system, distillation plant, a micro gas turbine and a heat transfer system. The method was developed at DTU for improving performance of human machine interfaces of alarm systems, but has spread in application to fields of fault diagnosis, planning and control, supervisory control, system design and risk analysis.

The project funded by the DHRTC to increase water treatment productivity, aims at developing a decision support system (DSS) software and applying it to a water treatment pilot plant at Aalborg University in Esbjerg. The software will employ MFM models of the pilot plant, and a diagnosis and reasoning algorithm. The DSS system will present anomalies with the most probable cause and possible consequences.

Modular architectures in large scale construction

Niels Henrik Mortensen, Professor, DTU Mechanical Engineering, Section of Engineering Design and Product Development

Modular Architectures has in traditional manufacturing companies been the basis for significant cost reduction and been an enabler for reducing time to market for new products. This presentation will present the main principles of implementing modular architectures such as interfaces stable over time, cost/effective scaling of processes and product solutions, understanding sub supplier costs and end to end thinking from requirements to solutions and manufacturing. Many principles can be taken from traditional companies, but other principles are very different due to the low volume of products in construction industry. The presentation will show examples from large constructions industry and indicate that significant cost savings on activities (such as maintenance) and products are possible.

Two STAR-type unmanned wellhead platforms in the North Sea.

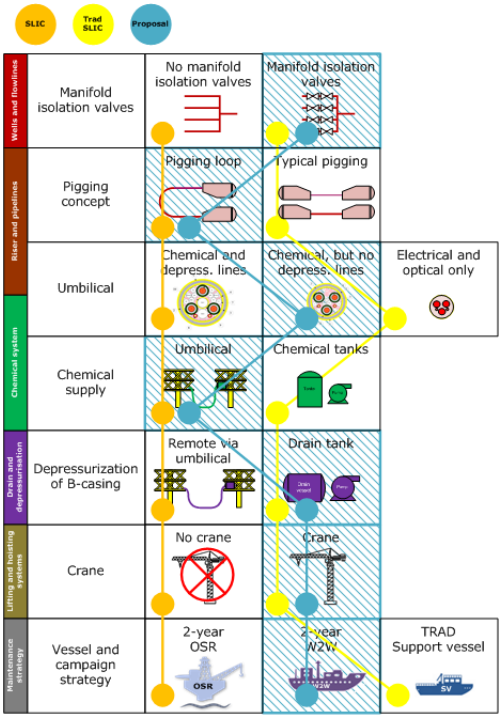
Cost savings for Well Head Platforms

Ulf Harlou, Senior researcher, DTU Mechanical Engineering

Kristine Wille Hilstrøm, PhD student, DTU Mechanical Engineering, DHRTC

Niels Henrik Mortensen, Professor, DTU Mechanical Engineering

A concept study on well head platform has been carried out in a co-operation between DHRTC and Maersk Oil and Gas. The basic idea has been to apply the industrial manufacturing paradigm on well head platforms. In many so-called cost out projects CAPEX are reduced, but OPEX are then in reality increased. The ability to quantify the consequences of selecting solutions is necessary in order to make the best compromises between CAPEX and OPEX. Therefore a very systematic CAPEX – OPEX balance evaluation technique has been developed. The following solution elements have carefully been considered: number of isolation valves, pigging concept, umbilical design, positioning of chemical tanks, chemical supply, depressurizing and crane availability. The study indicates that significant cost reduction possibilities are obtainable.



Systematic evaluation of CAPEX and OPEX

External corrosion management

Andreas Proschowsky, student, DTU Mechanical Engineering

Kim Bo Kristiansen, student, DTU Mechanical Engineering

Niels Henrik Mortensen, Professor, DTU Mechanical Engineering

A pilot study of external corrosion maintenance on topside facilities has been carried out. The idea was to apply a systematic quantitative approach for analyzing corrosion maintenance and quantifying variance in efficiency of activities. The analysis is the first step in creating a structured architecture for the maintenance activities at Maersk Oil and Gas. The study identifies and examines the operational principles and preconditions influencing corrosion maintenance and seeks to adapt maintenance strategies to the physical characteristics of each maintenance task.

The study presents indications of significant variance in corrosion maintenance efficiency between assets and that some manning principles for maintenance tasks are better than others. The study also shows the importance of data integrity between systems as well as the consequences of loss of information to the ability to perform operational excellence.

The conclusion was that the approach is feasible for further studies of activities in Maersk Oil and Gas.

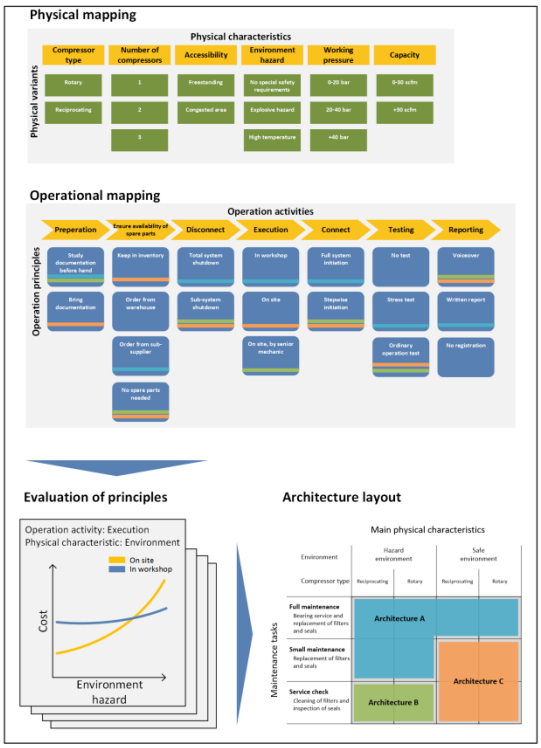


Illustration of the main concept of creating a maintenance architecture

Danish Hydrocarbon Research and Technology Centre
Technology Conference 2016

Breaking waves in the North Sea - a Maersk perspective

Jesper Tychsen, Maersk Oil and Gas, Esbjerg

Following the discovery of a photo and video documentation of two extreme plunging breaking waves in 2012 occurring at 45m water depth in the Danish North Sea sector, a large study has been undertaken to detail the probability of occurrence of extreme non-linear irregular waves and clarify their impact on loads and reliability of structures in the Danish Tyra field. The multi-discipline work has included development of a joint probability model of extreme storms/sea-states (long-term) and an 9 month wave basin test program to support development of a semi-empirical fully non-linear sea state model (short-term). All individual models of static and environmental loads, response and multi-failure mechanism resistance have been assembled in a complete Monte Carlo (MC) simulation format. The MC set-up has been applied to analyse 1 million lifecycles for each Tyra structure to estimate the annual collapse probability. The work has been presented in details in the OSRC 2016 conference. The present presentation will highlight selected findings and frame the challenges related to reliability of structures exposed to loading from extreme fully non-linear irregular waves.

Condition-based life extension and inspection planning (RBI) for offshore platforms

Ulf Tygesen, Rambøll

Due to business and national interests in prolonging the production of oil and gas for longer than initially anticipated, the majority of the installations in the Danish North Sea are likely to remain in operation for yet another significant period of time. The management of ageing is crucial, and it is important to realize that ageing really is not about how old the infrastructure is, but rather what we know about its condition and the factors that influence the onset, evolution and mitigation of its degradation. Innovative approaches for life extension and long-term management and control of ageing offshore assets are hence required.

The key discipline for managing the ageing of offshore structures is Structural Health Monitoring Systems (SHMS). Associated new advanced analysis methods of today range from smart sensors, intelligent networks, non-linear system identification, expansion processes, probabilistic FEM updating, wave load calibration, quantification of uncertainties (Bias and CoV), re-assessment analysis to Risk- and Reliability Based Inspection Planning (RBI). New methods combine latest development from a number of other related disciplines ranging from Electrical Systems, Control Systems, Machine Learning, Data Mining, to Value of Information (VoI) supporting the decision making processes, etc. The adoption of novel technologies drives the technological progress from lab testing on scaled models to full scale testing in the field under real conditions. The need for analysis of huge data sets from the SHMS requires for the latest development within Big Data processing by Cloud Computing solutions. Today's available computational power enables extracting of information from measured data, which was not possible for just a few years ago. SHMS based methods have the potential for extensive increase in the life of ageing platforms, reduction of maintenance costs, and at the same time reduction of uncertainties, increase in safety and hence constitute a suit of methods for reliable managing and controlling of the ageing processes for many years to come. Case stories of application of the today's novel methods will be presented for offshore platforms in the Danish North Sea.

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Structural Heath Monitoring of a Football Stadium Suspension Roof

Sandro Diord Rescinho Amador, *PhD, postdoc at the Centre and at DTU, Byg*

In this presentation, three key issues of a real-life vibration-based structural health monitoring system are discussed. The first is related to the estimation of the modal parameters of the monitored structures from output-only data together with their confidence intervals. The second key issue involves the automation of the modal parameter estimation. In fact, a successful assessment of the health condition based on modal properties is only feasible if these parameters are automatically extracted from the vibration raw data acquired over the course of a monitoring campaign. Finally, the third key issue concerns the detection of damage under varying environmental conditions. In real-life structures are subjected to changes in such conditions (e.g., temperature, humidity, wind, traffic, etc.). Therefore, if the modal parameter estimates are intended to be used as damage indicators, the variations induced by these conditions must be taken into account, otherwise they may mask the changes caused by structural damage. In order address the three aforementioned issues from a practical point of view, a study case of a football stadium suspension roof is presented.

Risk informed decision support in integrity management for offshore structures

Abstract

Michael Havbro Faber. SIR group, DHRTC - DTU

The economic potential for continued exploitation of oil and gas in the Danish part of the North Sea is considerable. However, a decisive factor for the feasibility of recovery of the remaining oil and gas resources concerns whether design service lives of the existing production infrastructures may be extended - safely and cost efficiently. Meeting this prerequisite constitutes a major challenge for structural integrity management and calls for a consistent framework for decision making, the best possible utilization of existing expertise and experience and a targeted acquisition of new knowledge.

Safe and efficient operation of offshore structures and facilities are generally challenged by harsh environmental conditions and difficult access. Moreover, damages to structures and facilities caused by fatigue crack growth and corrosion processes accumulate over time and impose risk to personnel, environment and operations. Despite considerable knowledge within the offshore engineering profession the uncertainties associated with available models for the representation of the performance of offshore structures are very significant and constitute a major cause of risks to personnel and environment as well as production. A major challenge of structural integrity management is to manage these risks consistently and efficiently and to document them transparently.

The theoretical framework for decision making subject to uncertainty is readily available since more than 50 years through the Bayesian decision analysis and Bayesian probabilistic modeling. This framework has by now been utilized at a relatively broad scale within the offshore oil and gas industry for more than30 years with considerable success. Probabilistic modeling, reliability analysis and risk assessments have by now gained full recognition as industry best practices for decision support in the context of assets integrity management and as basis for fulfilling regulatory requirements. Notwithstanding this success a more holistic utilization of decision analysis together with the development and use of advanced probabilistic modeling and analysis tools bear significant potential for further improvements of decision support.

In this presentation starting point is taken in an outline of the theoretical and methodical bases for risk informed structural integrity management for offshore structures, namely the Bayesian decision analysis together with selected elements of probabilistic engineering modeling, reliability analysis and risk assessment. Thereafter, supported by experiences from industrial projects it is highlighted how these approaches have been and are applied and an appraisal is provided on both their strong points and their potentials for improvements. Finally, the presentation is closed with a brief discussion of the potential benefits associated with a broader utilization of probabilistic modeling and risk informed decision analysis within the DHRTC.

Improved decision basis through uncertainty management

Abstract

Amina Aïssani, Sebastian Glavind, Drude Hundevadt, Arifian Augusta, Sebastian Thöns, John Dalsgaard Sørensen and Michael Havbro Faber. SIR group, DHRTC - DTU

The economical and societal importance of safe and well-functioning offshore structures, in conjunction with the large amount of resources allocated to their maintenance, indicate the criticality of decisions related to management of such structural systems. Moreover, when it comes to decision making affecting structural integrity over time horizons relevant for service life risk management, the uncertainty related to loading environment, deterioration mechanisms and system assumptions are significant and thus extremely important to consider.

In general, all uncertainties should be represented in accordance with the available knowledge, based on expertise, experience and evidence. I support of ranking of decision alternatives for structural integrity management, a proper decision framework must be established incorporating all the knowledge and related aleatory and epistemic uncertainties associated with the engineering models of physical properties, loading and functionalities of a structural system, and account for their evolution over time and space. The differentiation of the different types of uncertainties is irrelevant; a formal decision analysis necessitates that all uncertainties are considered and treated in the same manner.

Structural integrity management may at an abstract level be seen as a task of information management where information about the structural performance characteristics is achieved through collection and analysis of data related to loading and operation, laboratory experiments, strengthening, maintenance, monitoring and inspections. All acquisition of new information is however associated with costs which must be balanced by benefits in terms of service life risk reduction and increased recovery of oil and gas. Understanding these tradeoffs is paramount in structural integrity management as it facilitates the identification of where to focus future efforts of research.

In this presentation, some of the topics we are currently working on within our research group are presented; mainly (i) the identification of the dominant uncertainties that impact on the lifecycle performances of offshore structures, (ii) a review of recently developed probabilistic analysis methods that may facilitate the acceleration of analysis of how uncertainties affect the structural performance characteristics and (iii) the value of information analysis from decision analysis as an instrument to identify potentials for reducing uncertainty.

Nearshore test facility – understanding the extreme wave conditions

Thor Ugelvig Petersen, Head of Department, DHI

Flemming Schlütter, Senior Project Manager, DHI

A rapidly increasing number of facilities and part of the infrastructure of offshore oil and gas fields worldwide are approaching or have exceeded their original design life. Many of the platform are still producing substantial hydrocarbons at a profitable level. However, focusing on safety issues, the platforms may not be acceptable for extended operations without ensuring the technical and operational integrity of the structures. The structures were originally designed deterministically to withstand the prevailing environmental conditions, but must also be able to face extreme events with ample safety reserve. To measure and understand the physical processes, statistics and the accompanying structural response during extreme events, the need for a scaled test facility to accommodate the flow and structure interaction at a low scale is obvious. In an average year the Nearshore test facility must deliver storm wave data corresponding to 1000y or more at reference offshore location (DUC area in the North Sea). In conjunction with the latter a model scale of the Nearshore test centre is in the range of about λ = 1:8 – 1:10. The present presentation will focus on the setup, design, location and layout of the Nearshore test facility, and how the outcome of the measurements can ultimately support the incorporation of extreme wave events and their statistics in a probabilistic design.