# The CLEAN BIOCIDE project: Halophilic plant extracts as natural corrosion inhibitors and biocides for oil field application

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# Programme DHRTC Technology Conference 2021

Oil and Gas R&D towards 2050 – supporting the energy transition

## Tuesday 16 November

| Time | Activity |
|---|---|
| **10.00** | Registration and coffee |
| **11.00** | Welcome and introduction<br>**CEO Morten Willaing Jeppesen, DHRTC**<br>**Provost Rasmus Larsen, DTU** |
| **11.15** | Keynote: Energy transition through innovation<br>**Country Chair Denmark Martin Rune Pedersen, TotalEnergies** |
| **12.00-12.45** | Lunch<br><br>*DHRTC Meeting Place is open from 12:30* |
| **13.00** | Keynote: Innovation and the green energy transition<br>**CEO Anne-Marie Levy Rasmussen, Innovation Fund Denmark** |
| **13.45** | Coffee break<br><br>*DHRTC Meeting Place is open* |
| **14.15** | Break-out sessions:<br><br>A: Digitalisation: From Data to Decisions<br><br>B: Offshore Structural Integrity<br><br>C: Green chemicals |
| **16.00** | Coffee break<br><br>*DHRTC Meeting Place is open* |
| **16.30** | Panel debate: What role will R&D play for the energy transition in the North Sea?<br><br>*Participants*<br>• Renewables Explorer Denmark **Betina Jørgensen**, TotalEnergies<br>• Global Spearhead Director, Energy Field Development **Patrick Gilly**, Rambøll |

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| | • CEO **Glenda Napier**, Energy Cluster Denmark<br>• CEO **Morten W. Jeppesen**, DHRTC<br><br>Moderated by **Thomas J. Howard, Associate Professor and Head of DTU X-Tech** |
| **17.30 - 19.00** | Poster Session |
| **19.30** | Dinner |
| **21.30 - 00.00** | Networking |

## Wednesday 17 November

| Time | Activity |
|---|---|
| **9.00** | Keynote: Reducing the Environmental Impact of Oil and Gas Production<br>**Professor MSO Simon Andersen, DHRTC** |
| **9.45** | Coffee break<br><br>*DHRTC Meeting Place is open* |
| **10.15** | Break-out sessions:<br><br>A: Energy transition from an oil and gas perspective, abandonment, and Carbon Storage<br><br>B: Produced Water Management |
| **12.00-12.45** | Lunch<br><br>*DHRTC Meeting Place is open from 12:30* |
| **13.00** | Poster Session Award Ceremony<br>**Research and Educational Coordinator Lene Hjelm Poulsen, DHRTC** |
| **13.30** | Keynote: CCS – perspectives in the Danish North Sea<br>**VP Morten Gjetting Stage, TotalEnergies** |
| **14.30-14.45** | Closing remarks<br>**CEO Morten Willaing Jeppesen, DHRTC** |

# Breakout sessions: detailed descriptions

Day 1 – November 16th

## Theme

Digitalisation: From Data to Decisions

*Chair: Jørgen Næumann, DHRTC*

### Subtheme

From Digitisation to Digitalisation – From Data to Decisions

Presenter: Thomas Martini Jørgensen, DTU Compute

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### Subtheme

Estimation of Shear Sonic Logs in the Heterogeneous and Fractured Lower Cretaceous of the Danish North Sea using an Artificial Neural Network - A Case Study

Presenter: Mads Lorentzen, GEUS

Shear wave velocity information is valuable in many aspects of seismic exploration and characterization of reservoirs. However, shear wave logs are not always available due to cost and time-saving purposes. In this presentation, I demonstrate a tailored artificial neural network supervised learning approach to estimate shear wave velocity from well log measurements in the Lower Cretaceous section in the Danish North Sea. I use a limited well-log dataset from six wells in the Valdemar and Boje fields whereof four wells comprise the training set for the artificial neural network model, and two wells are used for testing. The limits of the algorithm are explored and analysed, and the main results are compared with a calibrated empirical rock physics model.

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## Subtheme

Digitalising geological surveying in support of Longyearbyen CO2 Lab, Svalbard

Presenter: Simon Oldfield, DHRTC

Fracturing in the overburden of CO2 storage reservoirs can present a risk for project success. In this study we combine use of a drone-mounted camera with traditional fracture mapping to characterise the 3D geometry of fracture networks.

Typically, fracture networks are mapped in two-dimensions and measured along one-dimensional intersections. We integrate field measurements with detailed three-dimensional scene reconstruction to build a mesh and textures representing the three-dimensional geometry of fracture networks.

By comparing the nature of these observations in across a larger spatial area, we aim to understand larger-scale controls on fracture geometry distribution across the structure of the area.

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## Subtheme

Applying Model Predicitve Control and advanced instrumentation to improve and waste water treatment in offshore oil fields

Presenter: John Bagterp Jørgensen, DTU Compute

We describe digitalization tools for the oil and gas industry to achieve zero harmful discharge to the marine environment while maintaining high oil production. We aim to stabilize and reduce hydrocarbon concentrations in discharged water as a case study to achieve zero harmful discharges from the oil and gas industry. Using engineering domain knowledge, we model the flow line, the three-phase separator and the deoiling hydrocyclones to simulate and control oil-in-water concentrations in the produced water while maximizing the oil production. We use novel sensors for the oil-in-water concentration, grey-box modelling techniques and model predictive control that combines real-time data and simple process models to simultaneously stabilize and maximize the oil production rate while respecting constraints on the oil-in-water discharge concentration. The developed system will be tested using industry standard digital twins as well as in a physical flow loop.

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**Subtheme**

Multilevel Flow Modelling – A knowledge representation framework to support plant safety, operation, and maintenance

Presenter: Xinxin Zhang, DTU Electrical Engineering

Multilevel Flow Modelling (MFM) is an AI knowledge representation method that brings process design knowledge and operation experiences into a formalized modelling framework. MFM method enabling automatic causal reasoning based on process data, counteraction proposal and barrier analysis. MFM based analysis is compatible with human cognition and can support decision making process during plant safety assessment, re-design, operation, and maintenance. This presentation will introduce the MFM method, and its current research activities funded by DHRTC.

## Theme

Offshore Structural Integrity

*Chairs: Ole Andersen and Ulla Hoffmann, DHRTC*

**Subtheme**

Fatigue of offshore structures

Presenter: Alexander Michel, DTU Civil Engineering

Fatigue has been widely recognized by the industry as well as the research community as an essential element in the design, maintenance, and repair of offshore steel structures. However, the traditional S-N approach only predicts the end of service life for a given detail, i.e., the time it takes for a fatigue crack to reach a critical size related to fatigue failure. Thus, for probabilistic inspection planning, additional information is required. In particular, experimental data on crack development, i.e., crack size versus fatigue damage, provide means for more economic inspection planning.

## Subtheme

### Innovative Structural Health Monitoring and Risk Informed Structural Integrity Management

Presenters: Evangelos I. Katsanos and Sandro Amador, DTU Civil Engineering

During their lifetime, offshore structures can be exposed to extreme weather conditions, which are associated with unusual big wave events. Such excessive loads may compromise the safety and integrity of those energy-related infrastructures and increase their susceptibility to structural failures. In this context, the deployment of a Structural Health Monitoring (SHM) system can safeguard both the structural integrity and the normal operational conditions of such structures. The benefits of deploying SHM systems to this kind of infrastructure triggered the conception and elaboration of an ambitious and promising R&D project, which is entitled “Innovative Structural Health Monitoring and Risk Informed Structural Integrity Management (InnoSHM)” and funded by the Innovation Fund Denmark (IFD). The InnoSHM project focuses on the development of Digital Twins as well as on the use of advanced System Identification Techniques, Big Data technology and Risk Management, aiming to support the development of a real-time SHM system and a data-driven decision support platform.

It is expected that the InnoSHM will allow early-stage damage detection and, in turn, improve maintenance and integrity management of offshore structures. The ultimate goal of InnoSHM is to enable the operators of the offshore structures to know immediately after a hazardous event if anything critical has happened to the structures and, thereby, effectively and safely support critical decision-making processes. The execution of such a demanding project required the synergy between academia and industry. Hence, a consortium has been formed consisting of the Danish Hydrocarbon Research and Technology Centre (DHRTC), Technical University of Denmark (DTU), Aalborg University (AAU) as well as TotalEnergies, Ramboll, and Brincker Monitoring ApS. The state-of-the-art techniques to be developed within the InnoSHM framework and the knowledge acquired can be readily applied to different types of structures, for which the digitalization of structural health management is a dominating trend.

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## Subtheme

### Detailed analyses of waves and wave loads and perspectives to offshore guidelines

Presenter: Erik Damgaard Christensen, DTU Mechanical Engineering and Thomas Kabel, Aarhus University

The presentation will give a review of the research over the last years funded by DHRTC on extreme wave loads.

This will also include a review of a sub-part of the design process of offshore and ocean structures and bridge the gap from the latest research to industry. The focus is on fixed structures, but much of the review is also valid for floating structures. Even though the estimation of the environmental conditions (for instance long term statistical conditions for waves) are important, the topic is believed to have gained a huge amount of interest during the last 3-4 decades and therefore has matured to a high level. Research is however still on-going with focus on joint estimation of extreme values for environmental variables (e.g. joint distribution of wave height and wave period). The translation of the wave conditions to forces has gained a lot of interest during the last couple of decades, however the knowledge seems not to have influenced guidelines for design of offshore structures. As an example, we can mention that the force coefficients in guidelines often refers to tests performed approximately 40 years ago, and not published in the open research literature.

The presentation includes a prototyping process of the research and development under *"Structural Integrity and Lifetime Evaluation"* under DHRTC. The prototype has the draft name "*CodeWrapper*". Late 2020 it was recognized that an overview of research and state of praxis, i.e., typically guidelines, was needed to have a focused plan for the next steps in the research and development and hereby bridging the gap between academia and industry.

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## Theme

Green chemicals

*Chairs: Yanina Ivanova and Kitt Ravnkilde, DHRTC*

### Subtheme

Biomass based chemicals for the oil industry

Presenter: Christian Marcus Pedersen, University of Copenhagen

Societal demands have pushed industries to consider the use of alternatives to chemicals of fossil origin. Besides the obvious advantages, such as a reduced $CO_2$ food print and lower pollution from the production, this development has also paved the way for chemicals with improved or even new properties. In this talk, our result from an ongoing project on biomass based $H_2S$ scavengers will be discussed. These scavengers are currently compared with the commonly used triazines in terms of scavenging efficiency. The chemicals are based on a sugar core, which increase safety in handling and lower environmental impact significantly compared with the chemicals used in production today.

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**Subtheme**

## The CLEAN BIOCIDE project: Halophilic plant extracts as natural corrosion inhibitors and biocides for oil field application

Presenter: Mette Hedegaard Thomsen, Aalborg University

Offshore oil production is subjectable to internal corrosion, which can occur through microbiologically influenced corrosion (MIC) caused by biofilm forming sulfur-reducing bacteria (SRB). To mitigate MIC, the oil and gas industry relies primarily on biocides and mechanical cleaning.

Halophytes (salt-tolerant plants), produce a variety of bioactive compounds and some of these compounds have antimicrobial activity. MIC was studied on carbon steel coupons inoculated with anaerobic sediment from the Wadden Sea (Denmark) to mimic MIC from oil production facilities in the North Sea. The coupons were treated with extracts from selected halophytes. Using H2S as activity indicator for SRBs and ATP for general microbial activity in the liquid phase, initial trials have shown a significant reduction in H2S conc. in experiments treated with extracts, compared to controls, indicating a reduction of SRB species. Next generation 16S rRNA amplicon sequencing of DNA from Bacteria and Archaea, proved a significant shift away from SRBs in the microbial composition when compared to samples not treated with extracts. Visual reduction in corrosion was observed on coupons. Long-term solutions to prevent MIC using natural antimicrobial compounds from halophyte plants are beeing developed in this study.

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**Subtheme**

## Green corrosion inhibitor: a new approach for eco-friendly corrosion inhibition of steel in the oil and gas industry

Presenter: Rajan Ambat, DTU Mechanical Engineering

Inhibitors are cost effective and efficient way of corrosion prevention; however, they lead to environmental hazards. Eco-friendly (green) inhibitors is a new path for inhibitors that are compatible with nature while also performing their anticorrosion functions. Green inhibitors also provides sufficient inhibitory effects without environmental hazards. For example, natural extracts of fruits peel, plant seeds and plant extracts have adsorption properties of an effective inhibitor and can be used in a more ecofriendly manner due to their biodegradability and non-toxic nature. Aloe Vera is one example of an environmentally friendly inhibitor which is rich in several organic compounds of high molecular weight with heteroatom and Π center electrons in their molecular structures. This talk will elaborate on some green inhibitor investigations for reducing CO2 corrosion in oil and gas.

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### Subtheme

Taking clues from pitcher plants - nanofilaments to protect oil well infrastructure

Presenter: Tobias Weidner, Aarhus University

Corrosion and scaling have tremendous impact on oil well maintenance intervals involving high economic and environmental cost. Silica nanofilaments (SNFs), modelled after the self-cleaning structure used by pitcher plants, can potentially protect well pipe surfaces from contact with production fluid. We have recently developed a simple SNF coating that can repel water and emulsions by maintaining a liquid layer of oil within its nano-silica network. The SNFs are self-cleaning and are expected to protect pipes from scale formation, biofouling, and corrosion. Within our recent DHRTC projects we have performed lab tests of the stability of different coating designs. While several designs failed, it became clear that silica ($SiO_2$)-based nanofilaments, would be stable under flow conditions expected within oil well pipes. Stability and performance make SNF coatings a potential candidate for efficient pipe well designs.

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## Day 2 – November 17th

### Theme

Energy Transition from an oil and gas perspective, abandonment, and carbon storage

*Chairs: Charlotte Nørgaard Larsen and Christian Husum Frederiksen, DHRTC*

## Subtheme

### A plugging system from autonomous setting of polymer microspheres

Presenter: Anne Ladegaard Skov, DTU Chemical Engineering

When a well reaches the end of its life, it must permanently be plugged and abandoned. The main challenges which have been reported associated with the plugging of wells can be categorized as unconsolidated formations, high temperatures, formation permeability, changes in formation strength as a result of depletion and tectonic stresses exerted by formation (e.g., shear stress and subsidence). The objective of this project is to develop a novel environmentally friendly polymer-based plug that has low gas and water permeability, long-term durability, and the capability of in-situ formation and autonomously setting when there is flow and a rough surface. As it is depicted in the figure, the mechanism of setting of the plug is based on the reaction of surface-functionalized polymer-based microspheres which condense them into a solid via the covalent bonds. The microspheres are based on a polymer that has high strength and very low gas and water permeability. Moreover, the deformation of elastic microspheres in response to the pressure difference over the plug will lead to an elimination of most of the porosities within the network of microspheres such that an almost impermeable plug will form.

The low permeability will hinder the wear of polymer and thereby increase the lifetime of plug. Therefore, the developed novel system can be regarded as a suitable permanent plugging material that could withstand the well conditions for a long period.

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## Subtheme

### Scale as Part of Well Barrier and Scale Generation

Presenter: Tanzila Sharker, Aalborg University

For abandonment of wells there is a need for sealing the upper part of the well, which is typically done by cementing. This work investigates the possibility of using induced scaling techniques for sealing wells as an alternative to current methods. Two main aspects are investigated, the ability of induced scale to function as a plug and the ability of scale to function as a barrier material when combined with normal cementing. Scaling is induced by applying an electric current to the metal, which has previously been shown to form non-porous scales in marine environments, known also a seacrete/biorocks.

A laboratory flow-setup is used for scale development at temperature and brine compositions resembling that of the Dan field, but at ambient pressure. A Direct

Current is applied to the pipe (acting as a cathode) wherein the scale is to be formed and an anode deployed in proximity hereof. The imposed current and the presence of an anode accelerates the scaling process.

Subsequently the sealing capacity of the scale and scale/cement plugs are tested to determine the applicability of scale as a sealant. This testing will include both sealing capacity regarding gas leaks as well as mechanical strength due to the requirement to withstand well pressures.

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**Subtheme**

## Efficient plugging of abandoned reservoirs using polymers

Presenters: Henning Osholm Sørensen, DTU Physics and Nico Bovet, DHRTC

The oil fields in the Danish North Sea are aging and some will have to be abandonned in the near future. We need to find solutions to improve the process of closing down wells in a safe, cost-effective manner to protect the marine environment and ensure well integrity.

It might be beneficial to seal off the reservoir formation itself prior to the abandonment process to stop residual fluids from flowing into the borehole. This could provide *easier and safer working conditions* during the closing of the well when cement is poured and cured. Thereby, ensuring a better quality of the cement sealing plug. In the long run, the integrity of the sealing will be enhanced because the pressure has been removed from the reservoir fluid on the barrier. Therefore, the method can reduce the environmental and abandonment risks and potentially reduce cost of the closing operations.

We currently synthesize and investigate properties of organic polymers intended to close the pores of the chalk formation. We will follow the sealing and polymerisation process inside bulk chalk by in-situ X-ray tomography and monitor the evolution of the polymer seal over time when exposed to high pressure and temperature (reservoir conditions) to evaluate its longer-term integrity. With this cross-disciplinary project between chemistry and material characterisation, we intend to deliver a polymer formulation that can seal off a chalk reservoir formation at conditions relevant for the DUC sector of the North Sea.

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**Subtheme**

## Can $CO_2$ be stored in depleted oil chalk fields?

Presenter: Hamid Nick, DHRTC

Many countries have committed to reduce their $CO_2$ emissions by ratifying the Paris Agreement. Carbon Capture and Storage (CCS) has been identified as a technology that is particularly suitable for decreasing the $CO_2$ levels during the energy transition from fossil fuels to renewables. Although the number of dedicated CCS projects is slowly increasing, the majority are still carried out in combination with Enhanced Oil Recovery (EOR). CCS has also been embraced in Denmark, where several climate and energy institutions emphasize that capturing and storing the $CO_2$ is essential for the mid-term achievement of the emission reduction targets and for becoming carbon neutral in the long term. The recent North Sea agreement, which sets 2050 as the end for the Danish oil and gas production and urges the $CO_2$ storage in the depleted hydrocarbon fields, represents an important step towards the deployment of CCS technology. However, because of the reactivity of calcite, main constituent of the Danish chalk fields, in the presence of $CO_2$-saturated water, $CO_2$ storage has mainly been considered for sandstone formations. Nonetheless, the global deployment of $CO_2$ storage can benefit from diversifying the lithology options. Thus, by reviewing the literature on $CO_2$ storage in chalk, mostly in connection with EOR, and by extrapolating from the knowledge on other type of carbonates (e.g., limestone), we discuss the main challenges and enablers for $CO_2$ storage in chalk fields in terms of the storage mechanisms, site safety, injectivity, and monitoring. Many of our observations for chalk may be relevant for other tight carbonate-rich formations.

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## Subtheme

Renewable energy driven integration of hydrogen in the Danish O&G sector

Presenter: Anders Køhler, Floating Power Plant

We have investigated the possibility of replacing natural gas with renewable energy produced on site, thus reducing the CO2-emissions from O&G production. The results show emissions reduced by 60-70%. In the project the partners also investigated the use of hydrogen to smooth out renewable energy intermittency and the export of excess renewable energy as hydrogen mixed into the natural gas produced. This technology could make the energy for offshore facilities fossil-free in the future.

# Theme

## Produced Water Management

*Chair: Jørgen Næumann, DHRTC*

### Subtheme

Towards zero harmful discharge

Presenter: Peter Christensen, TotalEnergies

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### Subtheme

Fast evaluation of synergistic effects of combinations of production chemicals in PW oil droplet stability

Presenter: Liridon Aliti, DHRTC

PW is well known to contain both dispersed and dissolved oil species. The ease of dispersed droplet removal is related to the droplet stability towards coalescence. The performance of many oil field chemicals is related to the surface activity of these and the easy of dispersing these species into the oil-water system being produced. Optimization of the formulation of each product (say a down hole injected corrosion inhibitor. CI) normally do not necessarily take into account the influence on performance downstream. Therefore, cocktails of chemicals (e.g. CI + a demulsifier) may end up in the PW stream and affect the performance of the droplet removal processes by either increasing or decreasing stability. In this work we report a number of microfluidic studies of these effects and how mixtures of chemicals affect coalescence frequencies and droplet behavior, and therefore eventually the performance of a PW treatment system depending on oil-drop removal. The findings can be explained through the interfacial behavior and departure from optimal OiW instability conditions due to under or over dosage of chemicals or significant competitions of chemicals both by differences in diffusion coefficients and the ability to adhere to the interface. The microfluidic approach has the advantage over bulk experiments (bottle tests) that mixing is fast and effects of diffusion is limited.

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### Subtheme

Towards Zero Discharge of Spent and Unspent H2S Scavengers

Presenter: Marco Maschietti, Aalborg University

The removal of hydrogen sulfide (H2S) from the gas produced offshore in the Danish North Sea is carried out by direct injection of aqueous solutions of a scavenger, MEA-triazine, which reacts with H2S giving substantially less harmful species, being mainly monoethanolamine (MEA) and dithiazine (DTZ). Oil and gas operators inject the scavenger in large excess of the stoichiometric requirement, in order to ensure the H2S concentration is brought down to safe levels.

Downstream of the pipe where the scavenging reactions take place, a water stream containing the unspent scavenger and the reactions products (spent scavengers) is separated from the gas. The handling of the spent and unspent scavengers (SUS) is problematic due to high pH and fouling potential. For this reason, the SUS are often directly discharged into the sea. This is far to be optimal as it represents a loss of value, due to large amounts of unused MEA-triazine, and it contributes to a large extent to the environmental impact factor of offshore oil and gas production.

This presentation focuses on the results obtained in the first year of the project "Zero Discharge of H2S Scavenging Chemicals". The project aims at developing a new process based on a combination of a membrane separation unit and a hydrothermal oxidation unit. The purpose of the membrane unit is to recover the unspent fraction of the SUS, while concentrating the spent fraction which is conveyed to the hydrothermal oxidation unit. The experimental results discussed in this presentation were obtained on real offshore SUS samples retrieved in the Danish North Sea.

Three commercial nanofiltration and one reverse osmosis membranes were tested at laboratory scale for assessing their capability of removing the organic pollutants from the SUS and of separating the unspent from the spent fraction. One nanofiltration membrane (NF270) showed the best results when considering the efficiency of TOC removal (65%), the high permeate flux and the capability of separating MEA-triazine from DTZ. The NF270 membrane did not show remarkable fouling over 24 hours of operation.

With regard to the hydrothermal oxidation process, the experiments were run on a 100 mL reactor at low severity (200 °C, 80 bar) and high severity (350 °C, 220 bar) conditions, under excess of oxygen. The reactive process was studied for different reaction times in the range 1 to 360 min. It was found that the three main constituents of the SUS (MEA triazine, MEA, and DTZ) are rapidly decomposed, while the COD of the water can be reduced up to 84% at low severity and 98% at high severity. The nitrogen contained in the water is mainly transformed into ammonium and nitrates, while the sulfur is oxidized to sulfate. The high-severity process shows reaction rates approximately 70 times higher than the low-severity process, which leads to a low footprint reactor compatible with offshore installations.

## Subtheme

### Towards zero harmful discharge – toxicity drivers, testing, and assessment approaches

Presenter: Lars M. Skjolding, DTU Environment

Produced water is a major waste stream resulting from offshore oil extraction. Produced water consist of a multitude of different compounds ranging from naturally occurring substances such as PAH, BTEX, and phenols originating from oil to production chemicals such as biocides, corrosion inhibitors and $H_2S$ scavengers added to maintain operations in accordance with legislative requirements. This creates a complex mixture of compounds that needs to be assessed in terms of potential environmental hazards. Currently, the assessment is carried out either as a substance-based approach that summarizes the toxicity of individual chemicals in the mixture or a whole effluent approach that tests the toxicity of the whole sample.

The presentation will combine the findings of an extensive literature review of the ecotoxicity of produced water and identified drivers of environmental hazards with practical off-the-bench considerations for ecotoxicity testing strategies. This is aimed at providing regulatory relevant and reliable input the current risk assessment approaches for produced water. Furthermore, the presentation will discuss pitfalls and limitations of current hazard assessment data used to populate the exposure assessment and provide specific recommendation for overcoming this through physical, chemical, and biological testing mainly related to standardized ecotoxicological test setups.

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## Subtheme

### Biofilm-based treatment for produced water

Presenter: Henrik R. Andersen, DTU Environment

Produced water (PW) represents the largest volume waste stream generated in oil and gas production operations. PW has a complex composition, which includes various production chemical residuals and naturally occurring organic and inorganic chemicals that are recalcitrant and difficult to remove. PW treatment would make it possible to meet future stricter regulation and achieve zero harmful discharge into the sea. Physico-chemical and bioremediation methods utilized for removal of these compounds have shown various operational problems, such as generation of toxic gases, phase transfer of pollutants, residual sludge production and the impossibility of destroying refractory compounds. An additional problem offshore is the footprint of most treatment systems are generally unacceptable for an oil production platform. PW treatment facilities on land using traditional biological treatment have been struggling with fluctuations in water quality parameters, which makes treatment results unstable.

The potential of Moving bed biofilm reactors (MBBRs) to treat PW from various oil production have been shown in previous research. It appears bacteria in biofilm are vastly more robust to toxicants and variable salinity and pH as well as more capable to degrade complex organic molecules. In Denmark, a large pilot plant is currently operating in connection with the oil terminal in Fredericia and a full-scale system will be built in the coming two year.

In a current research project in DHRTCs produced water management program, a 3-stage MBBR system using AnoxKaldnes™ K5 carriers (Figure 1) with attached bacteria adapted to high salinity is being refined for biodegradation of organic compounds present in offshore PW. Due to space constraints at offshore platforms, this MBBR is intended to be located on the seafloor taking advantage of the higher pressure and potentially utilizing the higher temperature of PW (~30-40°C) to achieve even faster reaction rates compared to known land-based systems. The established biofilm-based reactors were tested with different operational changes such as temperature (10 °C and 40°C), hydraulic loads and salinity while testing PW from different offshore platforms. Consistently, MBBR is able to degrade organic molecules such as toxic and persistent chemicals (including yellow and red list compounds) by adapted bacteria that are effectively retained in the reactors by the biofilms. The removal of pollutants concurs with whole water toxicity reduction.