

Final Report:

“Reservoir wettability and its effect on water-based recovery processes”

**The National
IOR Centre
of Norway**



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Theme: 1/Task: 1/Project: 13

Reservoir wettability and its effect on water based recovery processes

Post-doctoral project report

By: Iván Darío Piñerez Torrijos.

Motivation

The purpose of this project is to understand the parameters affecting both the initial wettability in carbonate reservoirs and the potential for wettability alteration by water-based EOR methods. These parameters also influence the potential for water-based wettability alteration processes, which will give opportunities for Enhanced Oil Recovery (EOR) effects during “Smart Water” injection and hybrid EOR processes.

The initial wetting of a reservoir sets a limit for the EOR potential during “Smart Water” injection. For this reason, an improved understanding of the factors influencing the wetting can help to control and better forecast oil production during water-based floods. Therefore, improvements in the field of Special Core Analysis (SCAL) to correctly assess reservoir wettability are needed; to preserve and reproduce the original reservoir wettability is a challenging task. Wrong core restoration procedures can lead to incorrect and scattered wettability results and thus induce serious interpretation errors when evaluating oil production profiles and the EOR potential of a reservoir system.

The oil and gas industry is currently underestimating the value associated to the reservoir chemistry of the three main reservoir phases, crude oil, brine and rock, to describe initial wetting and wettability alteration processes during oil production. The project had focus on creating robust experimental designs and protocols of core restoration to correctly assess and confirm wettability and wettability changes by advanced core analyses.

An adequate determination of reservoir wetting is crucial for obtaining a successful depletion strategy to maximize oil recovery. The project will focus on carbonate reservoir systems and important aspects of core restoration. The most relevant topics of this research project are core cleaning, core restoration, wettability estimation and its effect on oil recovery.

Project framework

The framework of this project was fully aligned with the main core objectives of the National IOR Centre. It consisted of work that aimed to improve the understanding of the oil recovery processes, with focus on water injection in carbonates. The project was conceptualized to create new opportunities in the future for production optimization, i.e., injection strategies or nouvelle forecast tools.

By studying reservoirs initial wettability, this project will also impact on the Smart Water field. This is due to the fact that the Smart Water potential is strongly linked to the initial wetting state of a reservoir. It is strategic for the National IOR Centre to acquire a broad understanding in the matter due to the environmental and economic opportunity that it represents for Norway. The use of Smart Water will minimize the CO₂ footprint derived from water injection projects and it will pre-condition oil reservoirs for further chemical EOR flooding, with the advantage of increasing the efficiency of chemical EOR injection.

The project contributed to several milestones in the roadmap of The National IOR Centre of Norway, including development of IOR methods, understanding IOR mechanisms, and it will be important in the decision making process of future EOR projects in the Norwegian Continental Shelf (NCS).



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Objectives:

To gain new knowledge about the components controlling initial wettability and the wettability alteration process and understanding how these parameters control oil recovery in carbonates. This knowledge will serve as a tool to design even smarter injection brines and will open new opportunities for EOR injection strategies. This knowledge can also be used to create better oil production forecasts.

To optimize core cleaning and core restoration procedures for obtaining a more representative wettability in the laboratory. The generated knowledge on core restoration and initial wettability will be used to increase the data quality used in SCAL and simulation studies and will provide an improved understanding of the effect of reservoir wettability on recovery processes and Smart Water EOR potential.

Executive summary

The project addressed different aspects of wettability in carbonates. Being the most important, core cleaning, core restoration, adsorption processes, and their effect on oil recovery processes. The work successfully expanded the available experimental information on these important topics. The project produced reliable experimental data that can be used to understand and explore waterflooding recovery processes. The knowledge gained represents a technical advantage in understanding general trends and deviations observed in core restoration, SCAL analyses and waterflooding processes. The data produced will be available through the published papers.

The results derived from this work can also serve as support for the creation of databases, models, simulations, parametric studies, or for validation purposes. This “new knowledge” and potential applications can serve for early detection of EOR opportunities as Smart Water injection, chemical EOR, or hybrid EOR methods. Additionally, the project has contributed to a significant improvement of SCAL by presenting nouvelle solutions in the field, especially in core cleaning and restoration protocols.

Oil recovery processes are complex since they involved interactions among oil components, brine composition and reservoir mineralogy. We strongly believe that experimental work is the most reliable way to study these processes, and this was a powerful reason to focus the project on experimental work.

Adsorption studies on carbonates were carried out, the initial wettability of the crude oil-rock-brine system was tested under different amounts of crude oil exposure and significant differences were observed on wettability and oil recovery processes. The main observations of this research line were that Polar organic components (POC) adsorption is a rather fast process, and that as the rock is exposed to more crude oil, the system behaves less water-wet. Moreover, the initial wetting appears to have a dramatic impact on the oil recovery profile since the systems that produced more oil under a forced imbibition process were the systems with higher water-wetness. This is a fact that appear to be in full contradiction to the general accepted premise associated to oil recovery processes that suggests that maximum oil recovery is reached at mixed wet conditions.

For comparison purposes the effect of acidic polar organic components adsorption on initial wetting was evaluated in both, the silica rich chalk from Aalborg and the carbonate pure Stevns Klint chalk material. The effect of initial wetting on oil recovery was also tested. The findings showed similar trends in terms of adsorption, crude oil exposure and recovery profiles, despite the fact that differences were observed in terms of surface reactivity and wettability due to the presence of silica components in the Aalborg chalk material.

A major breakthrough occurred in the research line of carbonate cleaning and core restoration, the project achieved the reproduction of core wettability on carbonates at core scale. The process consisted in the optimization of cleaning solvents selection, solvents injection, establishment of initial water saturation, and crude oil injection. The combination of all these aspects helped us to achieve wettability reproduction in a second restoration with a low error difference of 1.5 to 3.6% OOIP relative to the first restoration.

The project has provided to the National IOR Centre an important backbone on wettability research in carbonates with 50 research items associated to this post-doctoral project in the form of journal articles, conference papers, master and bachelor theses, posters, forums and other dissemination activities. This project was at the front-line of research in the field of wettability and was capable expanding the current knowledge and achieve a significant breakthrough in the field of core restoration. The research team that participated in the project expects to further disseminate these findings with the objective of causing a larger impact in the academia and industry.



Reservoir wetting is important since it governs in-situ fluid distribution in the pore system, effecting capillary forces and fluid flow in porous media, as well as influencing special core analyses (SCAL) for capillary pressure (P_c) and relative fluid permeabilities (k_{ro} and k_{rw}). The rock wetting state imposes an indirect effect on well rates and limits of economic hydrocarbon production [1]. The success of a waterflood operation in a carbonate reservoir is highly dependent on the initial reservoir wetting, which is the result of a chemical equilibrium established over geological time.

Currently, reliable estimation of in-situ reservoir wettability continues to be an elusive objective despite long-termed efforts and integration of cutting edge technologies for this purpose [2-5]. Integrating wettability measurements in reservoir engineering studies is a critical task because this single parameter has a tremendous impact on recovery factors, reserves estimation and profitability of commercial projects. Low quality data in wettability assessments can produce erratic results that can lead to underestimation or overestimation of recoverable reserves [3], it can also promote unrepresentative wetting states in restored carbonate cores, giving rise to scattered wetting states in SCAL experiments.

As long as the desired goal of in-situ wettability measurements is not reached, Special Core Analyses (SCAL) will continue to serve as the standard practice to quantify reservoir wettability [6, 7]. However, its precision, reproducibility and repeatability stand out as weak points for the current accepted SCAL practices. Wettability can be highly affected by drilling fluids, especially the ones bearing surfactants, or by fluids with different pH values than that of the formation [8, 9]. Core sampling routines aim to reduce native fluids loss associated to pressure and temperature changes during extraction and sampling.

This project offers a critical stance specially on the standard SCAL cleaning and restoration procedures, with special focus on the choice of inducing a strongly water-wet state, while suggesting an alternative solution to the challenging task of assessing reservoir wettability. Core cleaning and core restoration programs that can closely reproduce the native reservoir wettability can contribute to reduce uncertainty in the reservoir characterization value-chain.

Solvent cleaning methods are meant to efficiently remove hydrocarbons from the porous network but at the same time minimizing any possible damage onto the present minerals. Currently, the standard cleaning pair is toluene and methanol but many other options are available [7]. The use of different solvents can lead to different restored wettability states [10]. Thus, a correct solvent selection is crucial if preserved core samples are required to be restored to a representative reservoir wettability.

Furthermore, weaknesses of standard core restorations are coming to light [11]. Classical core cleaning methods have as objective to remove mud filtrates [12], precipitated salts and native crude oil to achieve a water-wet state.

However, by taking away the initially adsorbed polar organic components (POC) that dictate reservoir wettability with strong organic solvents, the initial wettability state is simply destroyed. Then, restoring initial core wettability in the laboratory becomes an impractical and difficult task. This is mainly due to the fact that the sampled reservoir crude oil used in core restoration processes might be different in its chemical composition from the oil that initially wetted the reservoir during the first oil migration [13]. Furthermore, the oil chemical composition may have changed during geological time due to adsorption and decomposition processes [14, 15].

Other important aspect of core restoration to consider is oil saturation. The presence of crude oil will expose mineral surfaces to surface active POC. Recent investigations had shown that POC adsorption takes place rapidly as crude oil enters in contact with porous media surfaces; it has also been shown that increased oil volumes reduce the degree of water-wetness of the restored cores [16-21]. However, outcrop chalks from different locations differ in mineralogy, especially silica content [22-25]. The mineralogical differences will affect available surface area and their surface reactivity, therefore affecting wettability processes. The role of non-carbonate minerals on chalk chemo-mechanical properties have been described as an important parameter that influences water-weaking processes [26-28].

In an experimental investigation by Hopkins [11], different chalk cores were exposed to different amounts of injected PV of the same crude oil, and it was reported that both water-wetness and spontaneous imbibition rate decreased for the core exposed to higher volume of crude oil. This suggests a correlation between chalk surface wetting and the crude oil quantity flooded through the material, a useful contribution to laboratory core restoration procedures [29].

This work aimed to confirm the previous results observed in pure carbonate surfaces and to expand this knowledge to the silica-rich Aalborg chalk material, to further confirm and compare effects of POC adsorption, wettability, wettability alteration and oil production. In the topic of core cleaning and restoration this project contributed with an important optimization work in the cleaning, restoration and wettability characterization processes. This led to the achievement of core wettability reproduction.

RELEVANT PUBLICATIONS

PAPER 1: Core wettability reproduction: A new solvent cleaning and core restoration strategy for chalk cores. *Journal of Petroleum Science and Engineering*.

Authors: Piñerez Torrijos, Iván Darío; Puntervold, Tina; Strand, Skule; Hopkins, Paul Andrew; Aslanidis, Panagiotis; Yang, Hae Sol; Kinn, Magnus Sundby. *Journal of Petroleum Science and Engineering* 2020; Volume 195.

Link: <https://doi.org/10.1016/j.petrol.2020.107654>

Summary

Laboratory core restoration procedures include different core cleaning solvents, establishment of initial water saturation (S_{wi}) by diverse techniques and processes of crude oil exposure that influence the final core wetting properties. In carbonate reservoirs, the acidic Polar Organic Components (POC) in crude oil are the main components dictating the wettability of the carbonate surface. Negatively charged carboxylates strongly attach to the positively charged CaCO_3 surface, thus acting as anchor molecules for the oil phase. During core cleaning with organic solvents, some of the adsorbed POC will be detached from the mineral surfaces, thereby changing the wetting conditions. However, cores are not expected to become completely water-wet even when using strong solvents. The main aim of this paper is to develop core cleaning and core restoration procedures to reproduce initial core wettability. Fractional-wet outcrop chalk cores were exposed to two different core cleaning procedures, (1) mild kerosene-heptane cleaning, or (2) standard toluene-methanol cleaning. Chromatographic wettability tests showed that both cleaning methods increased the fraction of water-wet surface area to a similar extent, but neither of them removed all adsorbed POC from the rock surface. Wettability tests by spontaneous imbibition showed that the kerosene-heptane cleaned core behaved slightly water-wet, while the toluene-methanol cleaned core behaved very water-wet, even though the cores had similar fractions of water-wet surface areas. Increased amount of crude oil exposure during core restoration reduced the water wetness below the initial fractional core wetting. Initial core wettability was successfully reproduced by combining mild cleaning solvents preserving initial adsorbed POC, and minimizing the amount of crude oil exposure during core restoration. Only a 1.5–3.6 % OOIP variation in ultimate recovery during spontaneous imbibition in four different core systems was observed.

CONCLUSIONS

This study compared the effect of two solvent cleaning methods on initially water wet chalk cores exposed to crude oil. The solvent systems studied were harsh cleaning with toluene and methanol, and a mild cleaning method with kerosene and heptane. The effects on wettability were measured by spontaneous imbibition and chromatographic wettability tests.

Oil recovery and capillary forces increased after cleaning the chalk cores with both systems. The harsh cleaning method resulted in higher ultimate oil recoveries than the mild cleaning. Thus, the toluene and methanol system appeared to have a greater solvation effect on the adsorbed POC on the chalk mineral surfaces.

The results suggested that the distribution of adsorbed POC on mineral surfaces is crucial in the activation or deactivation of capillary forces. Apparently, POC adsorbed at pore throats will have a greater impact on wettability than POC adsorbed onto pore bodies. Increased oil recovery together with highly efficient positive capillary forces were observed, even though minor changes were observed in the water-wet fraction measured by the CW tests. The combination of both spontaneous imbibition tests and chromatographic wettability experiments was crucial for this observation.

An injection of 5 PV of crude oil into a mildly cleaned core, showed reduced ultimate oil recovery compared to the first restoration. This effect did not allow the desired wettability reproduction to occur. **Figure 1.**

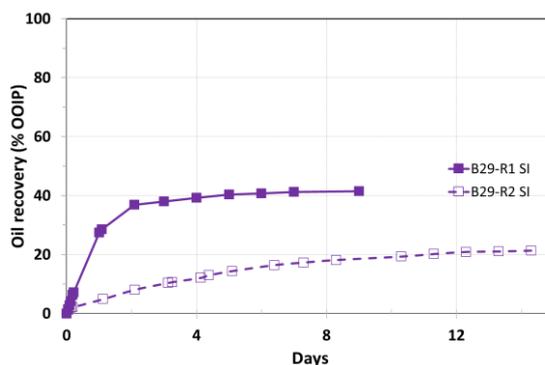


Figure 1. SI tests at 50 °C after initial restoration (R1) and second restoration (R2) in core B29. During R1 the core was exposed to 5 PV Oil B with AN = 0.36 mgKOH/g. After mild cleaning the core was exposed to another 5 PV of Oil B in R2.

Reproduction of initial wettability after mild cleaning was successfully achieved by injecting $(1-S_{wi})$ PV of crude oil by vacuum-saturation. SI tests at 50 °C resulted in an adequate match between the oil production profiles before and after using the optimized cleaning and restoration procedure. Differences of +1.5 - 3.6% OOIP were observed. **Figure 2.**

Minimizing solvent injection by kerosene and heptane reduced POC desorption from mineral surfaces that established the initial core wettability. In consequence the crude oil required to restore and reproduce the chalk cores wettability was reduced to $(1-S_{wi})$ PV.

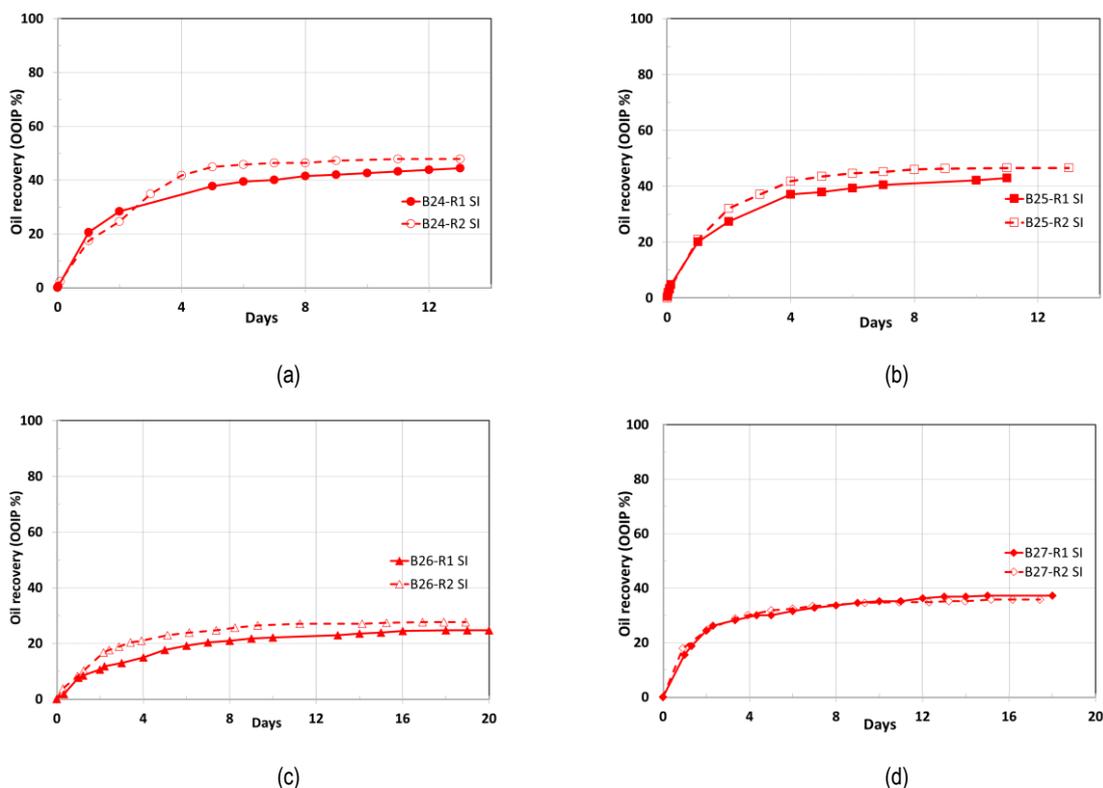


Figure 2. SI tests, $T_{tests}=50$ °C after initial restoration (R1) and a second restoration (R2) after optimized cleaning and restoration process. Cores restored with $S_{wi} = 0.1$. (a) Core B24 and (b) Core B25 exposed to Oil B (AN = 0.36 mgKOH/g). (c) Core B26 and (d) Core B27 exposed to Oil C (AN = 0.5 mgKOH/g).

The suggested cleaning and restoration procedure could potentially help to get closer to reservoir wettability in carbonate cores with similar mineralogy as chalk. The method can have a positive impact for wettability dependent SCAL analyses, which is critical for reservoir characterization studies.

Paper 2. Adsorption of Crude Oil Polar Components onto Silica-Rich Chalk and its Impact on Wetting

Isaac Klewiah; Iván Darío Piñerez Torrijos; Skule Strand; Tina Puntervold; Miltiadis Konstantinopoulos.

Paper presented at the SPE Norway One Day Seminar, Bergen, Norway, May 2019.

Paper Number: SPE-195603-MS

<https://doi.org/10.2118/195603-MS>

SUMMARY

Adsorption of polar crude oil components exert a major impact on chalk wetting, and adsorption effects have been reported on water-wet pure Stevns Klint outcrop chalk (>99% CaCO_3). Aalborg chalk is a silica-rich material also used as analogue rock material for chalk reservoir studies. This work aims to characterize the impact silica minerals will have on polar crude oil component adsorption, and core wettability. Silica-rich (6-8 At %) Aalborg chalk cores with initial water saturation (S_{wi}) of 10% were flooded with a crude oil with acid and base numbers (AN and BN) equal to 0.35 mg KOH/g of oil. Effluent crude oil samples were analyzed, detecting changes in the AN and BN concentrations at the core outlet. Wettability was determined by spontaneous imbibition (SI), and further confirmed by chromatographic wettability tests.

Adsorption of polar crude oil components was observed to be an instantaneous process. The adsorption of polar acidic components onto the Aalborg chalk surfaces was less profound as previously observed in Stevns Klint chalk. However, adsorption of polar basic components was significantly higher in Aalborg chalk, which could be explained by the presence of negatively charged silicate surfaces. The water wetness of the Aalborg Chalk core was significantly reduced after the crude oil exposure.

This comparative study on both Aalborg and Stevns Klint chalk highlights the impact of silica content on adsorption of polar components and initial wetting. The findings contribute with essential information for the development of theoretical and chemical models to describe initial reservoir wetting and explain oil production profiles in chalk reservoirs during normal water injections, or during wettability alteration with Smart Water.

Conclusions

The experiments conducted in this study showed the effect of silica (SiO_2) minerals present in Aalborg chalk on initial wetting. The results obtained from the experiments and subsequent analysis demonstrated that polar organic components (POC) in crude oil adsorbed instantly onto Aalborg chalk (AA) and affected its initial wetting. Wettability is therefore not dependent on the ageing time. Silica-rich Aalborg chalk adsorbed less acidic polar components than the pure CaCO_3 Stevns Klint outcrop chalk (SK), this could be due to the fact of the presence of Opal-CT, which can be observed in **Figures 3 a-b**.

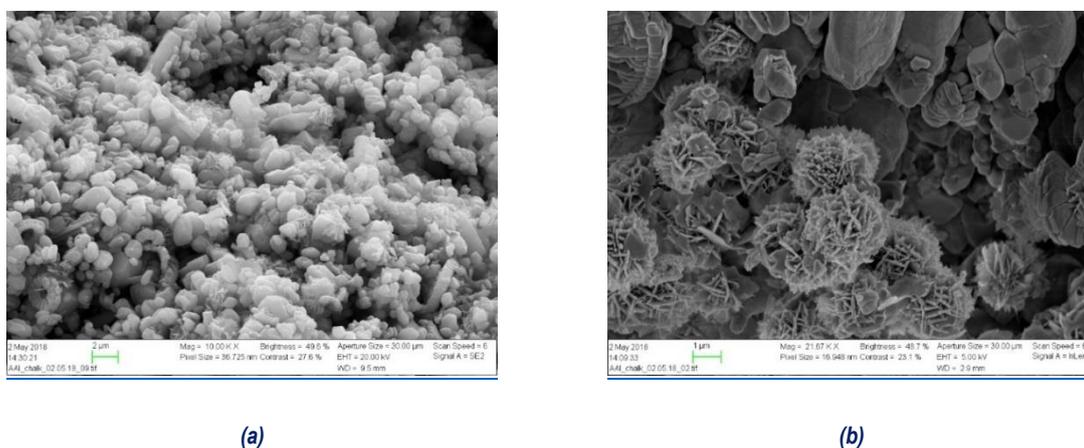


Figure 3: SEM images of Aalborg and Stevns Klint. (a) Preserved coccoliths in Aalborg chalk. (b) Opal-CT lepispheres.

From the SEM images, it appears that Stevns Klint chalk has no presence of Opal-CT, nevertheless coccoliths and their fragments are consistently spread all over the Stevns Klint porous media structure, **Figure 4**.

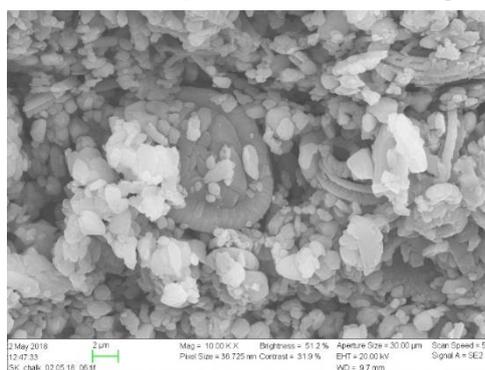


Figure 4. Stevns Klint chalk showing coccolith structures, and typical grain sizes of approximately 1 to 2 μm .

An intense adsorption of basic polar components onto silica-rich Aalborg chalk was observed. This suggests that adsorption of polar organic bases in silica-bound chalk is independent of the adsorption of polar organic acids. The base number and acid adsorption ratio ($\text{BN}_{\text{ads}}/\text{AN}_{\text{ads}}$) for Aalborg chalk was higher than that for Stevns Klint chalk and revealed silicates to be contributing to a large fraction of the available mineral surface in Aalborg chalk.

Chalk mineralogy influences the extent of adsorption of polar acidic and basic crude oil species. Previous studies by Hopkins examined the AN and BN adsorption onto Stevns Klint (SK) chalk. In their study, a Stevns Klint chalk core (termed SK-10) with S_{wi} of 10% was flooded with a crude oil with AN and BN = 0.40 and 0.35 mg KOH/g, respectively [30].

The adsorption results confirmed earlier observations by Hopkins et al. [30, 31], and the experimental procedures were thus reproducible. Since the adsorption is controlled by the prevailing chemistry of the crude oil-brine-rock system, a comparison to Aalborg; an outcrop chalk with different geo-chemical characteristics. The two core systems have similar physical characteristics, except for the large variation in specific surface area.

The adsorption of acidic and basic polar organic material onto Aalborg and Stevns Klint chalk was also compared by investigating the AN and BN effluent from the crude oil flooding of the cores AA#1 and SK-10, **Figure 5**.

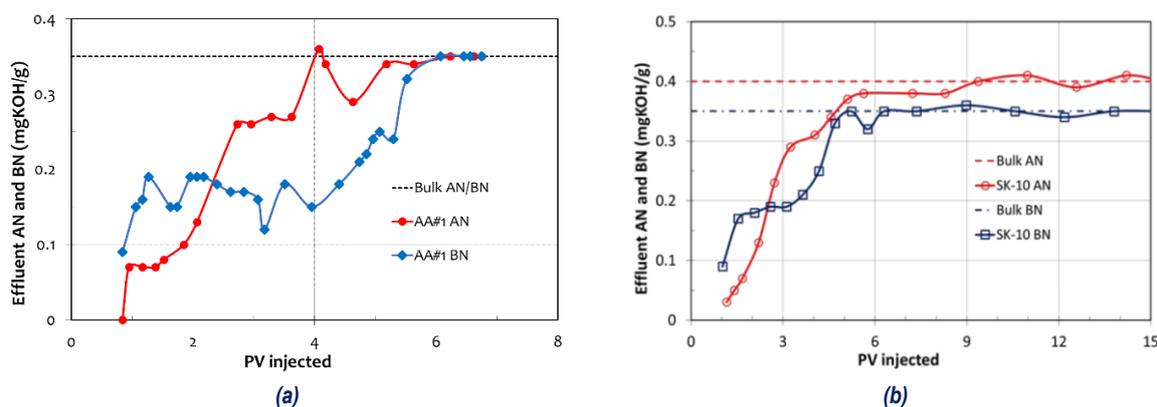


Figure 5: Effluent AN and BN from the crude oil flooding of (a) Aalborg chalk core AA#1 where $AN_{ads} = 0.83$ and $BN_{ads} = 1.02$, and (b) Stevns Klint chalk core SK-10 with $AN_{ads} = 1.33$ and $BN_{ads} = 0.93$. Data for SK-10 is obtained from Mjos, Strand [32].

In pure chalk, like Stevns Klint, the acids in the crude oil dictated the initial wetting when crude oils with increasing BN was used, as reported by Puntervold et al [33]. Adsorption of bases was explained as co-adsorption with the carboxylic acids. The results for Aalborg chalk containing a significant amount of silica minerals, portray the BN adsorption to be independent of AN adsorption. The high silica content in Aalborg chalk, introduces a new surface chemistry in the adsorption process that favours direct adsorption of some polar basic components present in the crude oil. In the Aalborg material, calcite and silicate-minerals co-exist and account for the differing AN and BN adsorption trends observed for Aalborg and Stevns Klint chalks.

The presence of negatively charged silica minerals on the Aalborg chalk surface further reduces the overall positive charge density in the Aalborg material, which will limit the ionic interaction between the negatively charged carboxylates and the Aalborg mineral surface. This phenomenon accounts for the reduced AN adsorption observed in Aalborg chalk as compared to Stevns Klint. Silica increases the specific surface area. The presence of silica, thus induces competitive adsorption between the polar acidic and basic components and plays a role in defining the initial wetting conditions of carbonates.

Paper 3 Effect of mineralogy on initial wettability and oil recovery from silica-containing chalk

Miltiadis Konstantinopoulos, Iván Darío Piñerez Torrijos; Skule Strand; Tina Puntervold; Isaac Klewiah.
81st EAGE Conference and Exhibition 2019
<https://doi.org/10.3997/2214-4609.201900956>

Summary

Carbonate rock wettability is influenced by polar components in the crude oil, rock mineralogy and brine composition. Previous studies on chalk suggest that exposure of a large amount of acidic crude oil to core material reduces water wetness, thus affecting the ultimate oil recovery achieved during waterflooding. Presence of silica in the pore space appears to affect the wetting state of chalk toward more water-wet conditions. This study evaluates the wetting effect of crude oil exposure on the silica-rich Aalborg chalk, and its impact on oil recovery.

Spontaneous imbibition and forced imbibition tests have been conducted at 50 °C to evaluate initial wetting and its effect on oil recovery from three silica-rich (6.8 At%) outcrop Aalborg chalk cores. Various amounts of crude oil were injected during core preparation, and it was observed that as the amount of crude oil injected increased, less water-wet conditions were obtained. A higher degree of water wetness in the Aalborg chalk core promoted higher ultimate oil recovery under forced imbibition than that previously reported for Stevns Klint chalk, containing low silica content. It was concluded that the silica content in the core induced a more water-wet wetting state in the core.

By comparing the results from the silica-rich Aalborg chalk material with those of the pure Stevns Klint chalk, it seemed like the silica present in Aalborg chalk affected the initial wettability of the chalk, making the Aalborg cores more water-wet than the Stevns Klint cores during core restoration.

For the Aalborg chalk it was observed that, as the amount of crude oil injected increased, less water-wet conditions were obtained. It was also observed that lower water wetness yielded lower ultimate recovery during forced imbibition, results that are in line with previously published work on Stevns Klint chalk, **Figure 6**.

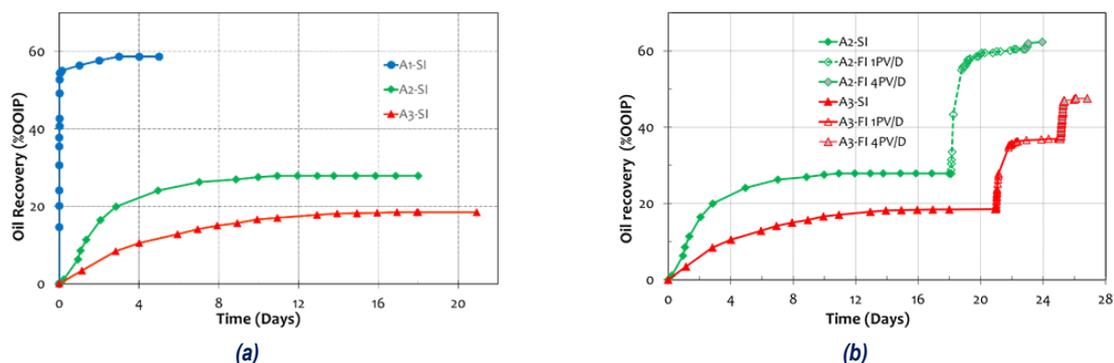


Figure 6. Oil recovery tests on Aalborg chalk cores restored with $S_{wi} = 0.1$ and various oils giving different initial wetting. Core A1 was exposed to heptane, while core A2 and core A3 were exposed to 5 PV and 8 PV crude oil, respectively. (a) SI test with VB0S (FW) as imbibing brine, followed by (b) forced imbibition (FI) with VB0S at a rate of 1PV/D and 4 PV/D. The tests on core A2 and core A3 were carried out at 50 °C, test on core A1 was performed at room temperature.

The recovery results are in line with the observations made by Hopkins et al. 2017 in their study on SK chalk material. The experimental results confirm that the initial core wettability established during core restoration has a significant effect on ultimate oil recoveries. The ageing time was the same for all cores, so the amount of crude oil flooded seems to be of significant importance, and dictates the initial wetting more than the ageing process itself.

The calculated wettability confirmed that the Aalborg chalk behaved more water-wet than Stevns Klint. When both core systems were exposed to an increased amount of crude oil, it was observed that the wettability decreased. These results are in line with previous observations showing that the presence of silica minerals, in the form of Opal-CT, affected the adsorption of polar organic components and the core wettability [34].

The results also showed that the initial core wettability had a significant effect even on oil recovery during the forced imbibition recovery processes. The Stevns Klint and Aalborg cores with the highest water-wet state, both showed significantly higher ultimate oil recovery than the less water-wet cores. Interestingly, these observed results are in complete contradiction to the work by Jadhunandan and Morrow (1995), reporting the highest oil recovery (and lowest S_{or}) at slightly water-wet conditions [35].

OTHER RELEVANT PAPERS

Paper 4. The role of polar organic components in dynamic crude oil adsorption on sandstones and carbonates.

Iván Darío Piñerez Torrijos, Aleksandr Mamonov, Skule Strand, Tina Puntervold
CT&F – Ciencia 2020 ;Volum 10.(2) s. 5-16 UIS
Link: <https://doi.org/10.29047/issn.0122-5383>

Paper 5. Impact of Temperature on Wettability Alteration by Smart Water in Chalk

European Association of Geoscientists & Engineers, Conference Proceedings, IOR 2019 – 20th European Symposium on Improved Oil Recovery, Apr 2019, Volume 2019, p.1 – 11
Iván Darío Piñerez Torrijos, Kristoffer G. Sæby, Skule Strand and Tina Puntervold.
Link: <https://doi.org/10.3997/2214-4609.201900178>



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PROJECT CONCLUSIONS

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This post-doctoral project shed light on different aspects of wettability and its effect on oil recovery, expanding the scientific literature available but also achieving a higher level of understanding of these processes. The main conclusions drawn from this project are:

The adsorption studies performed on carbonates, confirmed that POC adsorption is a rather fast process, and that as the rock is exposed to more crude oil, the system behaves less water-wet. Thus, the effect of adsorption on oil recovery is significant. Because it appears to have a dramatic impact on the oil recovery profile, the reservoir systems that produced more oil under a forced imbibition process were the systems with higher water-wetness. This is a fact that appear to be in full contradiction to the general accepted premise associated to oil recovery processes that suggests that maximum oil recovery is reached at mixed wet conditions.

The effects of crude oil adsorption and oil quantity on initial wetting were also tested in a silica-rich system. The findings showed similar trends in terms of adsorption, crude oil exposure and recovery profiles, despite having mineralogical differences. These differences had an impact on adsorption processes, surface reactivity and initial wettability due to the presence of silica components in the silica-rich carbonate.

The presence of silica impurities can change the surface reactivity of a rock surface by means of increased surface area and chemical reactivity. This phenomenon accounted for the reduced AN adsorption observed in the silica-rich chalk as compared to the pure calcium carbonate system. The silica presence induces competitive adsorption between the polar acidic and basic components and plays a role in defining the initial wetting conditions of carbonates. Therefore, it is recommended to run a thorough characterization of the pore surface mineralogy to correctly characterize and interpret the carbonate system wettability.

Carbonate wettability reproduction at core scale was successfully achieved in a second restoration process. The process engaged optimization of cleaning and restoration process. The combination of all these aspects help us to achieve the wettability reproduction in a second restoration with a low error difference of 1.5 to 3.6% OOIP relative to the first restoration in carbonate core material.

Temperature effects in the range of 70 to 110 °C during wettability alteration by Smart Water were investigated in a pure chalk from Stevns Klint. A model oil with an acid number (AN) of 0.6 mgKOH/g was used to establish an initial mixed-wet system in the core material studied. Temperature during Smart Water injection is extremely important, since the wettability alteration and the Smart Water EOR effect can be reduced by the reduced reactivity of Ca^{2+} and SO_4^{2-} ions towards carbonate mineral surfaces at lower temperatures.

Future plans

The way forward has different research lines but all of them can be potentially integrated, in the case of core restoration practices it is necessary to expand the research to carbonates with more complex mineralogies. This should be done to increase the confidence in the proposed protocol. Furthermore, it could be necessary to test if a third restoration can possible yield similar results or if the previously accumulated oil on the rock surface will require a specific cleaning method to achieve a third reproducible restoration. A way to solve this challenge is to investigate the POC retention and competition during cleaning and oil saturation, thus adsorption studies will complement these type of studies in a magnificent way.

This project contributed with different research tasks that are summarized in the published papers, a useful way to get a major benefit from this work can be found in the field of data analyses. However, before thinking of simulations and models, the information generated must be put in a specific data base oriented to analyze SCAL, wettability processes and oil recovery processes. Data analyses can provide to wettability and surface reactivity studies opportunities for brine optimization in oil recovery processes, or could potentially help to improve forecast tools or reservoir simulations in the near future.

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The main dissemination highlights of this project are summarized in the **table 1**.

Table 1. Count of dissemination activities in this project.

Journal papers	Conference papers	Master theses	Bachelor thesis	Seminars /symposiums/ Forums	Other activities	Total activities
2	6	11	2	18	11	50

For the detailed description of research items please visit Cristin.no by using the following link:

<https://app.cristin.no/persons/show.jsf?id=540435>

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