Pore-scale modeling of modified salinity water flooding

M. Farhadzadeh1, and H.M. Nick1

1Danish Hydrocarbon Research and Technology Centre, Denmark;

M. Farhadzadeh

AWF1

At the pore-level two-phase modeling, solid and liquids are clearly separated and two immiscible fluids (brine/oil) share the pore-space and flow. Here, a solver has been implemented to simulate two-phase flow, ions transport, ions adsorption on the chalk surface and dynamic wettability. This provides a framework of pore-level modeling to study flow behavior during immiscible displacement influenced by brine chemistry. In addition, the SEM image of chalk is used to mimic chalk pore-space geometry closely.

Keywords: Numerical simulator, EOR
Multi-scale multi-physics modelling of waterflooding in chalk

Simulation and Modelling team

Hamid Nick

AWF1

This poster illustrate the workflow developed for studying waterflooding in chalk reservoirs
Surface complexation models for the calcite-brine and brine-oil interfaces

Maria Bonto, Ali A. Eftekhari, Hamid Nick (DHRTC)

Maria Bonto

AWF 1

Different experimental studies have shown that modifying the injection water composition can improve the oil recovery from carbonate reservoirs. However, concurrent with the lab-work progress, predictive models at pore and core scale are needed to complement the experimental results, and to eventually serve as basis for a robust model for field scale applications. However, the positive effect on the production mainly stems from the interactions that occur at the mineral/brine and brine/oil interfaces. Thus, we first quantify these interactions by using surface complexation modeling. With this thermodynamic approach, we not only infer material balance data, but we can also predict the electrokinetic potential at these interfaces, a parameter that is tightly linked to the wettability, fines release or the mechanical properties of the rock.
Sector Modeling Study of Modified Salinity Waterflooding

Behzad Hosseinzadeh, Hamid Nick, Ali Akbar Eftekhar

Behzad Hosseinzadeh

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The model describes the benefits of the modified salinity waterflooding by changing the relative permeability which is obtained from history matched core flooding in the experiment by taking into account the effect of hysteresis. By preserving sector history and based on the different injection scenarios, the influence of modified salinity waterflooding has been investigated compared to conventional waterflooding.
Core scale modelling and experimental data analyses

Mirhossein Taheriotaghsara, PhD student at DHRTC, Ali Eftekhari, Hamid Nick

Mirhossein Taheriotaghsara

The impact of ionic modification on improvement of oil recovery at core scale is modeled using one dimensional transport flow system that is coupled with a surface complexation model. The obtained results from the model were compared with the performance of core flooding tests reported in the literature. Consideration of ionic interaction in terms of ion adsorption resulted in enhancement of model predictively. Also, the role of ionic adsorption in the appearance of oil bank in tertiary mode were explained.
Characterization of multiphase flow in fractured reservoirs using hidden physics models

Nikolai Andrianov and Hamid M. Nick

Nikolai Andrianov

AWF.1

We consider a two-phase oil-water flow in matrix-fracture system and choose a specific parametrized form of multiphase flow functions in matrix and in fractures. First, we assume that all parameters are known. We run simulations of this system using a conventional hydrodynamic simulator with a fixed set of parameters and use the obtained saturation field as a ground truth. Then, we represent the discretization of the governing equations as a Gaussian process and estimate its covariance function by minimizing the negative log marginal likelihood. The obtained parameters of the covariance function are used to close the system of governing equations.

We start with estimating the parameters of the Brooks-Corey relative permeability functions in the Buckley-Leverett equation. Next, we present results for a core flooding experiment, where the injected water is displaced in high permeability fracture and simultaneously imbibes into adjacent matrix blocks. We generate the ground truth solutions for various values of residual saturations, Brooks-Corey exponent, and capillary entry pressure at several time instants and estimate the parameters of fracture relative permeabilities and capillary pressure. Finally, we estimate how much does the accuracy of predictions deteriorate in case of a noisy training data.
An improved mechanistic model for the modified-salinity-water flooding of chalk reservoirs

Maria Bonto, Ali A. Eftekhar, Hamid M. Nick

AWF1

The available “mechanistic” models for the modified-salinity-brine flooding of carbonate rocks either take an empirical approach to the wettability alteration of the rock or can only fit a limited number of experimental data. Here, we use a new concept titled “available adsorption sites” (AAS), which describes the wettability alteration of the rock based on the availability of adsorption site that can host the polar groups of crude oil on the chalk surface. The model is tested against a large database of spontaneous imbibition data from literature with very promising results.
Analyzing the production chemistry data of the North Sea chalk reservoirs with a multiphase reactive transport model

Mirhossein Taheriotaghsara, Maria Bonto, Ali A. Eftekhari, Hamid M. Nick

Ali A. Eftekhari

Is the presenting author a research assistant/MSc/PhD student/Postdoc? No

AWF1

Production chemistry contains a wealth of data that describes the physico-chemical interactions between the injected water, formation water, crude oil, and reservoir rock. By combining a tuned surface complexation model for oil-brine and chalk-brine, a two-phase flow model, and published 4D seismic data, we try to explain the production chemistry data from a production well in the Halfdan field.
Core Flooding Studies

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We examine the effect of brine compositions, injection scenarios and temperature on oil recovery in Danish North Sea reservoir samples. In this work, a homogenous chalk core sample from the Tor formation was selected. Core was saturated with Halfdan formation brine and subsequently, Halfdan crude oil. Following that, the sample was aged at reservoir conditions (p \(=170\) bar and T \(=70^\circ\text{C}\)) for approximately 3 weeks. Several synthetic (representative) reservoir brines were injected into the aged cores at 0.1 cm\(^3\)/min to mimic fluid flow thorough porous media in the reservoir of interest (Nca\(\approx 10^{-7}\)) at T \(= 70^\circ\text{C}\) and 90 \(^\circ\text{C}\). Brines used in this study were equilibrated with CaCO\(_3\) at room temperature to minimize the effect of dissolution on oil recovery. During core-flooding, we monitored pressure differences across the core, volume of oil produced amongst other parameters. Insights into the role of brine chemistry were obtained through effluent analysis performed using an ion chromatography technique. Finally, preliminary geochemical calculations provide insights into rock-fluid interactions.

In a small scale core flooding setup, the method which is going to be used in long core flooding experiments will be screened beforehand. As small slices with a length of less than 2 cm and standard diameter are used in these experiments, the pore volume is more than 2.5 times less than the standard core plugs. Thus the amounts of materials (oil and brine) and also consumption of time are much lower than for longer core flooding experiments. The aging time is among the biggest challenges in core flooding. As aging time takes at least 2 or 3 weeks, considering another method to also reduce this time is desirable. Dynamic aging was introduced to be checked by small scale setup then. The effluent oil after injection were collected at a resolution of approximately one sample third pore volume, and analyzed by mass spectrometry. The results were used to see the pattern of adsorption of polar compounds of oil on the rock surface and verify the dynamic aging procedure.
Reservoir fluid Characterization

In North Sea reservoirs, petroleum is confined in large tight (1-5 mD) chalk fields. Water injection is typically employed to increase recovery; still, the recovery factor rarely exceeds 40%. Due to reservoir heterogeneity and subtle variations in oil composition and surface effects, different fields respond differently to injection programs. These processes are poorly understood, and the complexity makes development of improved EOR methods a challenging task.

To improve our knowledge of these intricate systems, we combine laboratory scale core flooding with analytical chemistry. We show how specific compound classes are preferentially adsorbed on the carbonate rock during the initial phase of the flood, and subsequently expelled by the injection gas. Compounds of low polarity, e.g. saturated hydrocarbons and polycyclic aromatics, remain in the fluid phase. Contrarily, heteroatom-containing compounds show surface interaction and retention. The selectivity is not only based on functional groups, but also on molecular size where steric and conformational effects seem to have an influence. These findings may tell us why certain fields produce better than others do, and may potentially lead to tailor-made EOR programs.

To further characterize the complexity of petroleum constituents, a novel material has been developed and utilized to separate the crude oil through π-π interactions. This novel technology has been shown to be capable of sequencing petroleum molecules based on the benzene ring size. This material has also been applied to the 2D off-line analysis of the crude oil. There is additional chemical information to be obtained from samples of crude oil from the Danish North Sea, which is complementary to SARA analysis and more arduous analytical techniques. π-π enhanced interaction materials support a potential solution for overcoming the challenges of separation.

Highly saline formation water from the subsurface is produced along with the petroleum fluid. The ions Na+, Mg2+, Ca2+ and K+ are present in the produced water in concentrations most often above 100 ppm. Hence, these are classified as bulk ions. Ba2+ and Sr2+ are present in sub-ppm concentrations and are thus considered trace ions along with other metal species present at ppb levels. All six elements are analyzed by a multi-step analytical procedure designed for high saline multi-component mixtures such as sea water and further optimized for petroleum fluids by combining IC and ICP-OES.
Rock-Fluid Interactions

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Aiming to define and understand the thermodynamics and kinetics of geochemical processes taking place during water-flooding of oil-saturated cores, a series of high resolution experiments were performed.

During the experiments a high-resolution profile of the effluent solution obtained during core flooding was obtained. Stevns Klint outcrop core as well as Dan and Kraka oil fields cores where sequentially flooded with formation water, seawater and ten time diluted seawater, enabling a detailed in-sight on the reactions taken place during the process.

Preliminary results show the presence of precipitation and dissolution reactions, as well as the presence of surface area reactions (adsorption) which take place during the complete flooding process and continuously alters the chemical composition of the effluent.

These results will be further used to calibrate existing reactive transport models by introducing real reactive transport data, aiming to improve further the predictions of oil recovery during water-flooding-EOR processes in the Danish North sea oil fields.

In an approach based on infrared spectroscopy, we are currently developing a reliable screening approach for the identification of residual oxygen- and nitrogen-rich organic constituents, the non-mobile and non-volatile compounds which adhere strongly to rock surfaces, for a series of representatively selected North Sea drill core samples. This experimental approach is based on attenuated-total-reflection infrared spectroscopy of thin films from extracted drill core samples, which have been separated carefully by solid-phase-extraction schemes. This spectroscopic screening approach so far provides a fast and robust method for a semi-quantitative detection of amines, amides and organic acids. The content of these polar compounds and especially the content of organic acids are suspected to play a crucial role for the fluid-rock interactions (the wettability properties) and consequently the oil recovery mechanisms.