The National IOR Centre of Norway

Final Project Report

1.1.1 DOUCS – Deliverable of an Unbeatable Core Scale Simulator

Project number and location: 100157 NORCE
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1. Executive summary

The developed EOR simulator, IORCoreSim, represents an important tool for interpretation of laboratory work and scaling of the results to field conditions. Uncertainty in scaling laboratory EOR results to the field scale reduces possibility for implementing EOR in oil fields. IORCoreSim seeks to improve interpretation of laboratory experiments with emphasis on scale and temporal dependency of involved physics. This allows for more robust scaling of experimental data from lab-to-field and thereby reduce uncertainty in predicted field scale EOR performance.

2. Introduction and background
   (Project initiation, tasks involved, collaboration (national and international), user partner involvement if relevant)

Numerous core floods to test traditional and emerging EOR methods have been performed for many decades. The big challenge is that the data needs interpretation. In the lab there may be significant end effects, the flow is linear rather than radial and the temperature is kept constant whereas in the reservoir there are temperature gradients. The purpose of this project is (1) to develop a core scale simulator that is capable of simulating most, if not all, EOR processes investigated in the lab, (2) interpret data and extract relevant parameters to be used in field scale models and (3) upscale lab scale experiments to grid block scale.

3. Results
   (Description and discussion, research-/user partner involvement)

The project has resulted in a reservoir flow simulator, IORCoreSim, with a focus on the laboratory scale. All upscaling of EOR starts with the interpretation of the laboratory results. By matching appropriate mathematical models handling the effect of experimental flow rate, core properties (permeability, porosity and core dimensions) and conditions (temperature, pressure), IORCoreSim can be used for investigation of large-scale behavior in small large-scale models.

Two ambitions in the development of mathematical EOR models in IORCoreSim have been to capture scale and temporal effects in the laboratory results, and to handle the effect of varying conditions (e.g., permeability, temperature). The models should be consistent with the underlying (pore scale) physics and experimental observations and have model parameters which are independent on varying conditions.

The main parts of IORCoreSim are listed in Table 1. The simulator consists of a basic two-phase flow model handling SCAL type experiments. This part computes the phase flow and development of pressure and saturation with time. The transport of species dissolved in the water and oil phases, and the EOR effects, are solved in a separate time step loop (operator splitting technique). The transport scheme can be implicit, explicit or automatic selected based on flow rate in local cells. An automatic time step method can be set to reduce numerical smearing of chemical fronts.

Table 1: Main parts of the IORCoreSim simulator.

Two-phase flow simulator
• Rectangular, radial or corner point grid to represent various experiments. • Sequential solution of flow equation allows proper handling of capillary forces at the core scale. • Open surface boundary conditions suitable for laboratory experiments. • Spontaneous imbibition boundary conditions.
Specie transport
• Options for implicit or explicit transport of species dissolved in the oil and water phases. • Saturation and porosity dependent diffusion using Archie's resistance model. • Interpolation based on specie concentration or adsorption, capillary number, pH or surface potential. Linear or tabular variation of interpolation parameter.
Temperature model
• Allows simulating experiments with changing temperatures. • Temperature effects included in all relevant models. • Corrects for thermal expansion.
Geochemical model
• Ion exchange (both cations and anions). • Dissolution/precipitation of minerals. • pH and surface potential + flash calculation of produced brine pH at measured temperature.
Polymer model
• Bulk viscosity model handling effects of polymer concentration, temperature and salinity. • In-situ rheology models handling shear thinning, elongational flow (shear thickening) and mechanical degradation. • Numerical integration of rheological behavior in large well blocks. • Chemical/thermal degradation.
Interpolation of saturation functions (kr and Pc)
• Handles the effects on oil recovery for various EOR methods like Low Salinity/Smart Water, wettability alteration and surfactant flooding. • Linear or logarithmic relative permeability interpolation. • Interpolation based on specie concentration or adsorption, capillary number, pH or surface potential. Linear or tabular variation of interpolation parameter.
Graphics
• Graphical post-processing options for grid data using ResInsight (OPM; http://resinsight.org/) or Eclipse utility FloViz (Schlumberger).

Polymer is the only EOR method explicitly mentioned in Table 1. The well-known mechanism in polymer flooding a reduction in the water mobility. The achievement of the polymer model in IORCoreSim is that the model can quantify the mobility reduction observed at different flow rates and at varying conditions with a single set of model parameters.

IORCoreSim is also an excellent tool for interpretation of low salinity and smart water experiments. Although the actual mechanism(s) in these methods is unknown, their EOR effect must in some way or another, be linked to the presence of ions, the pH and mineralogy of the rock surface. The geochemical model keeps track of the pH and ion history, and then various assumptions may be tested by using some geochemical property to interpolate the saturation functions. Most of the Smart water experiments published in the literature are of the spontaneous imbibition type. Such experiments are not easily simulated using commercial simulators. IORCoreSim offers special boundary conditions making simulation of spontaneous imbibition straight forward.

Additional EOR methods in IORCoreSim are a gel model suitable for silicate gel, a simple surfactant model and a microbial EOR model.

4. Conclusion(s)

The developed core scale simulator IORCoreSim has the capabilities necessary for simulating different experimental setups and interpretation of various experimental EOR results. It is a recommended tool for polymer, low salinity and smart water.

The use of IORCoreSim can contribute to a more robust scaling of experimental data from lab-to-field and thereby reduce uncertainty in predicted field scale EOR performance.

5. Future work/plans
   (Work in progress, journal papers in particular)
6. Dissemination of results
   (Include testing/implementation by research-/user partners if relevant)

The capability of IORCoreSim has been tested through its use in several projects conducted at NORCE. The types of problems addressed include interpretation of SCAL experiments from our core laboratory, water management using silicate gel, placement, and efficiency of scale inhibitors, behavior of associative polymers and time delay when measuring in-situ water pressure with a water wet probe. Through a cooperation with UiB and UiS in the project, several spontaneous imbibition experiments with varying boundary configurations have been simulated. This includes standard oil water experiments, effect of Smart water and some special experiments showing gel shrinkage due to imbibition into the matrix rock. IORCoreSim has also been used in four master theses conducted at UiS. The software, with user Manual and example input files, is available from the IOR Centre Teams pages under 7-Final deliverables/IORCoreSim.

Dissemination during the project is listed below:

- Nødland, O.M., Lohne, A., Stavland, A., and Hiorth, A., ”A Model for Non-Newtonian Flow in Porous Media at Different Flow Regimes,” ECMOR XV European Conference on the Mathematics of Oil Recovery, Amsterdam, Netherlands, 29 August - 1 September 2016
- Omekeh, A. Hiorth, A. Stavland and A. Lohne, “Silicate Gel for In-depth Placement: Gelation Kinetics and Pre-flush Design”, IOR Norway 2017 – 19th European Symposium on Improved Oil Recovery 24–27 April 2017, Stavanger, Norway

- O.M. Nødland, A. Lohne and A. Hiorth, "Simulation of polymer mechanical degradation in radial well geometry" IOR Norway 2017 – 19th European Symposium on Improved Oil Recovery 24–27 April 2017, Stavanger, Norway
- Andersen, P. Ø., Brattekås, B., Walrond, K., Aisyah, D. S., Nødland, O., Lohne, A., Haugland, H., Føyen, T. L. and Fernø, M. A. [2017] Numerical Interpretation of Laboratory Spontaneous Imbibition - Incorporation of the Capillary Back Pressure and How it Affects SCAL. SPE International Petroleum Exhibition & Conference, Abu Dhabi, UAE, 13-16 November. https://doi.org/10.2118/188625-MS.
- Lohne, A., Nødland, O., Stavland, A. and Hiorth, A. [2017] A model for non-Newtonian flow in porous media at different flow regimes. Computational Geosciences 21(December). https://doi.org/10.1007/s10596-017-9692-6.
- Andersen, P. Ø., Lohne, A., Stavland, A., Hiorth, A. and Brattekås, B. [2018] Core Scale Simulation of Spontaneous Solvent Imbibition from HPAM Gel. SPE Improved Oil Recovery Conference, Tulsa, Oklahoma, USA, 14-18 April. https://doi.org/10.2118/190189-MS.
- Sparebank 1 SR-Banks Innovasjonspris for 2017 awarded to A. Lohne and O. Nødland for the development of the simulation tool IORCoreSim and the implemented polymer model. Stavanger, 29. October 2018.
- IORCoreSim release party, 26 June 2017; executable code and sample simulation files were made available for members of the National IOR Centre, and an introduction course in usage of the simulator was given by O. Nødland.
- Andersen, P. Ø., Brattekås, B., Nødland, O., Lohne, A., Føyen, T. L. and Fernø, M. A. [2018] Darcy-Scale Simulation of Boundary-Condition Effects During Capillary-Dominated Flow in High-Permeability Systems. SPE Reservoir Evaluation & Engineering. https://doi.org/10.2118/188625-PA.https://doi.org/10.2118/188625-PA.
- Arild Lohne, Aksel Hiort and Oddbjørn Nødland, [2018], Flow simulator IORCoreSim - EOR potentials at core and field scales, FORCE lunch and learn 3. December 2018
- IORCoreSim release party, 26 June 2017; executable code and sample simulation files were made available for members of the National IOR Centre, and an introduction course in usage of the simulator was given by O. Nødland.
- Andersen, P. Ø., Lohne, A., Stavland, A., Hiorth, A. and Brattekås, B. [2019] Core Scale Modeling of Polymer Gel Dehydration by Spontaneous Imbibition. SPE Journal. https://doi.org/10.2118/190189-PA.
- Nødland, O., Lohne, A., Stavland, A. and Hiorth, A. [2019] An Investigation of Polymer Mechanical Degradation in Radial Well Geometry. Transport in Porous Media 128. https://doi.org/10.1007/s11242-018-01230-6.
- Lohne, A., Stavland, A. and Reichenbach-Klinke, R. [2019] Modeling of Associative Polymer Flow in Porous Medium. IOR 2019 - 20th European Symposium on Improved Oil Recovery, Pau, France, 8-11 April
- Updated IORCoreSim executable code and Users's manual available at IOR Centre Teams - Final deliverables, May 2021.

IORCoreSim applied in master theses:

- Chunlei Zhang, "A Study of Interplay Between Capillary and Gravitational Forces with Application to Oil Recovery in Naturally Fractured Reservoirs", UiS, 15 June 2016.
- Daisy Siti Aisyah "Modelling of co-current spontaneous imbibition – improved understanding of reservoir flow physics", UiS, 15 June 2017.
- Siri Sandvik, "Simulation of oil recovery by wettability alteration – interpretation of Smart water imbibition experiments at reservoir conditions", UiS, spring semester 2018.
- Jan Inge Nygård, "Simulation of Water Management Processes", UiS, 15 June 2019.

7. References