The National IOR Centre of Norway

Adding more physics, chemistry and geological realism into the reservoir simulator

Project 2.6.1

Project duration: January 2014 – November 2021
Project manager: Ove Sævareid (NORCE)
PhD students: Dhruvit S. Berawala (UiS, supervised by Pål Ø. Andersen, completed 2020)
Postdocs: Pål Østebø Andersen (UiS, 2014-18), Trine Solberg Mykkeltvedt (NORCE, 2014-19), Birane Kane (NORCE, 2018-21), Runar Berge (NORCE, 2019-21)
Other key personnel: Steinar Evje (UiS), Robert Klöfkorn (NORCE), Tor Harald Sandve (NORCE)

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Final Project Report

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1. Executive summary

This project has been ongoing throughout the lifespan of the IOR Centre, and the efforts have followed two lines of development. The team at UiS (Evje/Andersen/Berawala) has developed fundamental modelling concepts and tools, supporting a variety of IOR applications across different Tasks in the Centre. The activity at NORCE has contributed towards the Open Porous Media (OPM) Initiative as a proxy for "the reservoir simulator". During the early years, the project provided hands-on support to bring the bring the full field simulation capabilities of OPM up to speed. From 2016 onwards, this aspect has been cared for by dedicated industry support outside the Centre, and the project has since then promoted fundamental research on models and computational methods, conducted by postdocs. The topics investigated include higher order numerical schemes for polymer flow (Mykkeltvedt), simulation of non-linear Newtonian fluids (Kane), and flow in fractured porous media (Berge).

Each postdoc involved with the project has contributed an individual final report, and Berawala's PhD-dissertation is also available [2].

2. Introduction and background

The topic for this project dates to the formulation of Task 6: Reservoir Simulation Tools in the original Centre application, and the overall aim has been to provide modelling methodology and simulation capabilities for IOR processes. The project activity has been shared between UiS and NORCE, where model development has taken place at UiS, while NORCE has focussed on simulation technology.

The work of postdoc *Pål Ø. Andersen* at UiS has been motivated by the need for new and improved models for multiphase and reactive flow in porous media. Collaborations include UiS, UiB, NORCE and Equinor.

The PhD-dissertation of *Dhruvit S. Berawala* [2] has been investigating natural gas production from shale reservoirs. The work comprises two parts, basic modelling of production flow in fractured shales, and injection of CO2 for enhanced oil recovery. The work has been conducted at UiS and supervised by *Pål Ø. Andersen*.

Development of reservoir simulation tools has taken place related to several of the Tasks at the IOR Centre. The current project has been focusing on field-scale models, and the activity at NORCE has aligned itself with the Open Porous Media (OPM[1]) Initiative with the goal to contribute to an open-source reservoir simulation framework. Research results presented in terms of publicly available source code is a valuable supplement to traditional scientific publications and promotes reproducible computational science. Open-source development is well suited to foster collaboration across disciplines as well as institutions. An open codebase lends itself to extensions both in breadth (new application areas) and depth (more advanced features and functionality), thus supporting technological development and innovation.

Three postdocs have been involved with the OPM-related work at NORCE. Collaboration includes the OPM development network, as well as other open-source initiatives.

Trine S. Mykkeltvedt has explored the potential for applying higher-order discretization methods for reservoir simulation. By maintaining sharp fronts for saturations or concentrations, a more accurate account for the reservoir flow can potentially be obtained. The work also includes simulation studies related to CO2 injection for EOR purposes.

Birane Kane has focussed on direct numerical simulation of non-Newtonian fluids. Being able to solve these strongly non-linear problems on complex geometries, can provide guidance for correlations or surrogate models that can be incorporated as sub-models in large scale reservoir models.

Runar Berge has worked to improve the representations of fractures in porous media flow. Conventional modelling for industry relevant models is based on dual continuum models where the fractures are given an effective representation via dual porosity / dual permeability formulations. By incorporating the fractures more explicitly into reservoir models, a more detailed and realistic understanding of the reservoir behavior can potentially be obtained.

3. Results

In the early phase of the project, significant contributions to the OPM development including parallelization and performance as well as to simulation of polymer and CO2 injection scenarios. Code was released open source to OPM and DUNE[2] frameworks, and three NORCE researchers affiliated with the project also contributed to the OPM review paper [1].

[1] See https://opm-project.org/ and http://github.com/OPM.
[2] DUNE (https://www.dune-project.org/) Distributed and Unified Numerics Environment. Toolbox for solving partial differential equations.

Postdoc Trine S. Mykkeltvedt investigated the impact of higher order discretization schemes applied to reservoir flow, in particular polymer flooding. Advanced schemes of WENO type are demonstrated to be applicable for the complex meshes of real field models, leading to increased accuracy and reduced grid orientation effects. Also, a typical CO2-EOR scenario has been investigated, focussing on gravitational instabilities arising during miscible displacement.

Postdoc Pål Ø. Andersen has made original contributions to fundamental mathematical modelling of porous media flow. Building from sound physical basics and clear and principled reasoning, examples include generalised relative permeability formulation, fracture-matrix interaction ranging on scales from a single fracture to field scale modelling, and interpretation and upscaling of chemically reactive flow. The research has led to 15 papers in peer-review journals and numerous conference contributions.

Postdoc Birane Kane has been working with modelling and simulation of non-Newtonian (FENE-P, Oldroyd-B) viscoelastic fluids. Based on classical finite element methods, a simulation framework is made available via the open-source framework DUNE. Furthermore, physics informed machine learning, where traditional machine learning (e.g., neural networks) are supplemented by the explicit equations representing the flow physics, has been introduced as a tool for viscoelastic flow modelling.

Postdoc Runar Berge has made an advanced model (Discrete Fracture Matrix (DFM) model) designed for simulation of flow in fractured porous media, applicable on industry relevant models via OPM. Functionality has been demonstrated for the Smeaheia field model.

For all the postdocs, we refer to their submitted final reports for further details.

PhD Dhruvit S. Berawala [2] has advanced the understanding of the mechanisms governing gas production from shales, and which effects that dominate the flow behaviour under various conditions. In particular, the study of CO2 injection into shale reservoirs contributes modelling capabilities relevant for combining CO2 storage and methane extraction. The thesis is composed of four journal publications.

4. Conclusion(s)

The project has advanced state-of-the-art of reservoir modelling at a conceptual level as well as regarding simulation capabilities/technology. Simulation tools are made available via open-source code.

5. Future work/plans

At least two journal papers are in progress. Also, the generalised relative permeability concept developed by Pål Andersen, is currently under consideration for implementation in OPM. Significant amounts of future project activity are planned, building on the OPM codebase.

6. Dissemination of results

Significant contributions to open-source simulation tools are released, and a substantial number of journal papers are published. A three-day combined OPM introduction course and workshop for centre members were held October 2017.

7. References

[1] Atgeirr Flø Rasmussen, Tor Harald Sandve, Kai Bao, Andreas Lauser, Joakim Hove, Bård Skaflestad, Robert Klöfkorn, Markus Blatt, Alf Birger Rustad, Ove Sævareid, Knut-Andreas Lie, Andreas Thune.

The Open Porous Media Flow reservoir simulator. Computers & Mathematics with Applications, Volume 81, 2021, Pages 159-185, ISSN 0898-1221, https://doi.org/10.1016/j.camwa.2020.05.014.

[2] Dhruvit Satishchandra Berawala. ***Numerical Modelling of Gas Production and CO2 Injection in Tight Shale Reservoirs for Enhanced Gas Recovery.*** University of Stavanger, 2020 (PhD thesis UiS, no. 560) https://uis.brage.unit.no/uis-xmlui/handle/11250/2687118