The National IOR Centre of Norway
Post Doc report (Runar Berge), part of

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

Project 2.6.1

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Key personell: Tor Harald Sandve (NORCE)

Project duration: September 2019 – July 2021

Final Project Report

Field scale simulation of flow in fractured porous media

Project number and location: 2.6.1 NORCE
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PhD students and postdocs: Runar Berge (Postdoc)
Other key personnel: Tor Harald Sandve (NORCE)

1. *Executive summary*

Improved modeling methodology and simulation capabilities for IOR are important to perform reliable pilot and full field simulations. In this project, we contribute towards the Open Porous Media (OPM) (www.opm-project.com) simulation framework. This is an open-source code able of handling industrial relevant models, which provides a platform for testing innovative reservoir simulation developments in general. The current project addresses improved simulation tools, which are important for simulation of any IOR processes. In particular, the project focuses on extending the capabilities of OPM to handle state of the art fracture flow models. The new extension of OPM is flexible and can be used for a wide range of fracture flow models. Thorough testing of the implementation is done by comparison to well known benchmark cases. The project also demonstrates that it is possible to include fractures in reservoir scale industrial relevant models.

2. *Introduction and background*

Fractures occur in many reservoirs and can change the flow paths through a reservoir. Including fractures in a reservoir simulator poses several challenges. First, fractures may occur on all scales, from the pore scale up to reservoir scale. Second, the fractures have a huge aspect ratio where the aperture of the fractures may be millimetre thick, while the length of the fractures can span hundreds of meters. Third, the properties of the fractures can be significantly different from the surrounding reservoir rock. Specifically, the permeability of the fractures can be orders of magnitude larger than the reservoir rock. To efficiently handle these challenges, the right mathematical models must be used. The two main classes of models that handle fractured porous mediums are the Dual-Continuum models and the Discrete Fracture models. In the Dual-Continuum models the fractures are upscaled into an effective medium, and a transfer function is responsible for the mass exchange between the rock matrix and the fractures. The second class of models is the Discrete Fracture models. In these models the geometry of individual fractures is represented explicitly, thereby the name discrete. While the Dual-continuum models have seen some use in the industry standard reservoir simulators, the Discrete Fracture models have so far been mostly been limited to scientific simulation codes. Implementing a Discrete Fracture model in OPM will make these models available for industry relevant cases.

3. *Results*

The main result of this project is the implementation of a flexible framework in OPM that can be used to set up fractured flow models. The focus has been on including the Discrete Fracture Matrix (DFM) model in OPM, however, we also demonstrate that the same framework can be used for other fracture flow models such as the Dual-porosity/permeability model.

3.1 Multi-domain framework in OPM.

The multidomain framework implemented in OPM lays the foundation for most of the subsequent results. The multidomain framework developed allows for solving models that consists of multiple domains (with possible different governing equations) in OPM. The implementation is heavily inspired by the multi-domain implementation in DUMUX (https://dumux.org/). In the multidomain implementation, each domain can use separate OPM models and parameters. The domains are coupled together by mortar grids that can project fluxes and pressures from one domain to the other. The advantage of this framework is that it works a wide range of different fracture models. Specifically, we have tested the framework for the DFM and Dual-Permeability models.

3.2 Benchmarking DFM models in OPM for single phase flow and tracers.

The implementation of DFM models in OPM has been validated against the fractured benchmarks in the two benchmark papers [1] [2]. The results show that the implementation of the DFM model in OPM is consistent with other simulators that use the Two-Point Flux Approximation (TPFA) discretization. Fig 1 shows a comparison of a solution obtained with OPM and a reference solution.

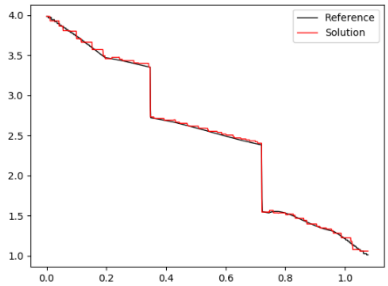

Fig 1: Comparison of the pressure obtained in OPM (red) and a reference solution (black) from Benchmark 3 in [2].

3.3 Two-phase immiscible DFM-models.

The DFM model developed in 3.2 has also been extended to include two-phase immiscible flow. Extensive testing and validation of the implementation has been done, e.g., we have reproduced the results from [3]. The two-phase model has also been used on a model of the Smeaheia field that included along fault flow. This is a large achievement and the first step in in moving from smaller scientific examples into making the DFM models applicable on industry relevant models.

3.4 *Consistent discretization of anisotropic materials*.

The industry standard discretization of the fluid flux is the TPFA method. The method is simple to implement, fast, and can handle the complex geometry that results from the corner-point grids of subsurface reservoirs. However, this method is known to be inconsistent for anisotropic materials and badly shaped grids. This is especially a challenge for DFM models, where the constraints from the fractures can be very complex and lead to badly shaped cells. There exists many different methods that tries to solve this issue, e.g., the

Multi-Point Flux Approximation (MPFA) method. A more recent method is the Diamond Scheme, which performed very well in the benchmark paper [4]. In this sub-result we implemented and tested the Diamond Scheme. The Diamond Scheme worked very well for 2D problems, however, for 3D problems it suffered from computational cost and large condition numbers. In addition, setting flux boundary conditions is not straight forward. From these results we can conclude that the scheme is not mature enough, but it is worth paying attention to as it is further developed.

3.5 PorePy – OPM coupling

In this sub-result, a workflow for coupling PorePy with OPM has been developed. PorePy (https://github.com/pmgbergen/porepy) is an Open Source reservoir simulator developed in Python that specializes on DFM models. PorePy has an extensive library for handling the geometry of fractures, and a robust interface to the meshing library gmsh (https://gmsh.info/). In the workflow developed, PorePy is used to create the meshes of the fractured domains as well as the projections between the rock matrix and the fractures in the DFM model. The meshes and projections are written to text files that can be read by OPM. This workflow allows us to create highly flexible meshes of complex fracture networks that can be used in any of the standard OPM models.

4. Conclusion

The main achievement of this project has been to implement DFM models in OPM. In addition, the flexible multidomain framework that were developed also allows for a greater class of fracture flow models, e.g., Dual Porosity models. The multidomain framework has been thoroughly tested and validated against analytical and reference solutions. The project also demonstrates that it is possible to run the DFM models on industry relevant models of reservoirs with complex corner-point grids.

In addition to the multidomain framework, a workflow that integrates OPM with PorePy is developed. This integration gives access to powerful methods for generating complex fracture meshes that can be used in OPM.

5. Future work/plans

Currently, we are finishing a paper on the implementation of DFM models in OPM. This paper focuses on how pressure dependent permeability of fractures can best be included into DFM models. The paper contains examples, from simple geometries constructed to improve the understanding of fractures in the caprock all the way up to real reservoir models.

6. Dissemination of results

All the implementation in this project is released open-sourced:
https://github.com/rbe051/opm-multidomain
https://github.com/pmgbergen/porepy
https://opm-project.org/

References

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