Benchmarking Tailored Formulations of Multiphase Flow in Porous Media

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Abstract

Due to the limited available information from the subsurface, numerical models are our most useful tool to estimate processes taking place at the underground. Nowadays, gas and nuclear waste storage, shale gas and EOR exploitation rise the necessity of understand and predict the fate of multiphase flows in the underground.

Various formulations for multiphase flow arise from different linear combinations of governing equations and choice of associated unknowns (Chen et al., 2006; Helmig et al., 1997). Each formulation has its own benefits and drawbacks; and the optimal may vary depending on the physics of each model. Therefore, a set of formulations, suited for the election of the user, have been implemented in COMSOL Multiphysics®. The flexibility of the Mathematics Physic interface allowed the efficient implementation of these complex differential equations in COMSOL Multiphysics. The formulations are able to model two-phase, variable density, miscible and immiscible fluid flows in all dimensions.

Currently, the equations of state of oil, water, brine and supercritical CO2 have been implemented although they can be easily extended to any other fluid. These formulations open a wide spectrum of possible applications for multiphase processes that can be combined with other physics to create multiphase multiphysics applications.

The available formulations have been verified against four well-known multiphase flow benchmarks: the Buckley-Leverett (Buckley & Leverett, 1942), the McWhorter (McWhorter & Sunada, 1990), the five-spot and the CO2 leakage through an abandoned well (Ebigbo et al., 2007) problems. The results show the capability of the implemented formulations to reproduced multiphase physical processes.

Reference

Buckley S, Leverett M. (1942). Mechanism of fluid displacement in sands. Trans AIME, 146,187 –96.

Chen, Z.; Huan, G. & Ma, Y. (2006) Computational methods for multiphase flows in porous media Siam, 2.

Class, H.; Ebigbo, A.; Helmig, R.; Dahle, H.K.;d Nordbotten, J.M.; Celia, M.A.; Audigane, P.; Darcis, M.; Ennis-King, J.; Fan, Y.; and others (2009). A benchmark study on problems related to CO2 storage in geologic formations. Computational Geosciences, Springer, 13, 409-434.

Ebigbo, A.; Class, H. and Helmig, R. (2007). CO2 leakage through an abandoned well: problem-oriented benchmarks. Computational Geosciences, Springer, 11, 103-115.

Helmig, R. & others. (1997). Multiphase flow and transport processes in the subsurface: a contribution to the modeling of hydrosystems. Springer-Verlag.

McWhorter, D. B. & Sunada, D. K. (1990) Exact integral solutions for two-phase flow. Water Resources Research, Wiley Online Library, 26, 399-413.

Figures used in the abstract

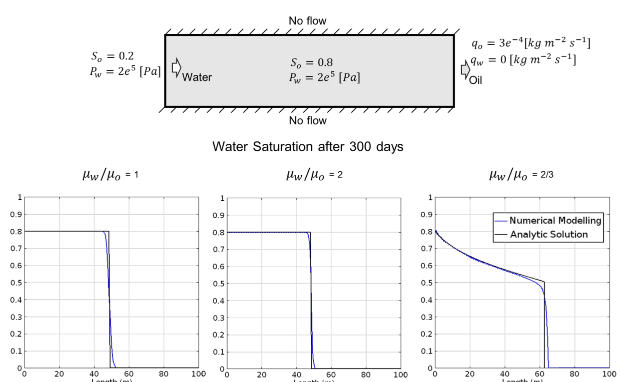

Figure 1: Conceptual model and modelling results of the Buckley-Leverett problem. Results for different viscosity ratios are presented.

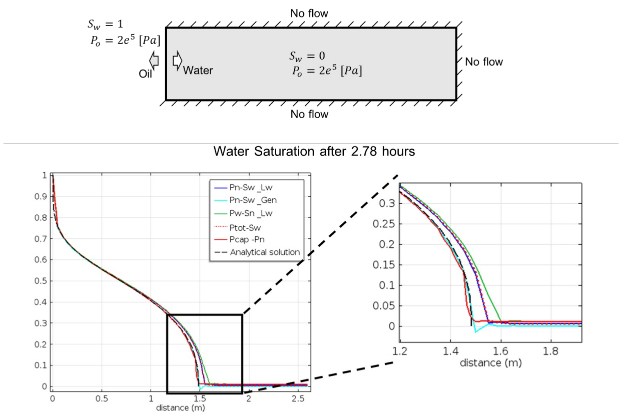

Figure 2: Conceptual model and modelling results of the McWorther problem. Five different formulations are compared with the analytical solution for the problem.

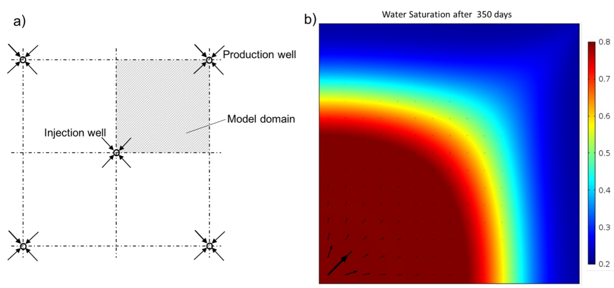

Figure 3: Conceptual model and modelling results of the five-spot problem. b) shows the water saturation in the domain and the velocity flow vector after 350 days of operation.

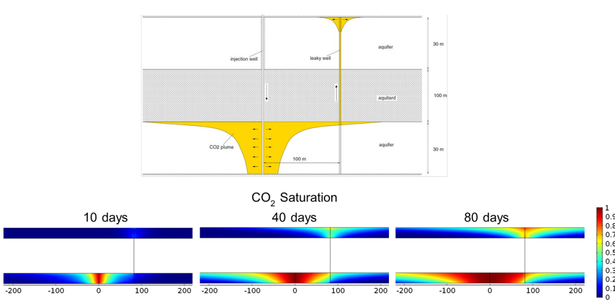

Figure 4: Conceptual model and modelling results of the CO2 leakage through an abandoned well problem. Results show the evolution of the supercritical CO2 in both aquifers. The sketch is reproduced from Class et al., 2009.