Numerical modeling of immiscible two-phase flow in micro-models using a commercial CFD code

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Introduction

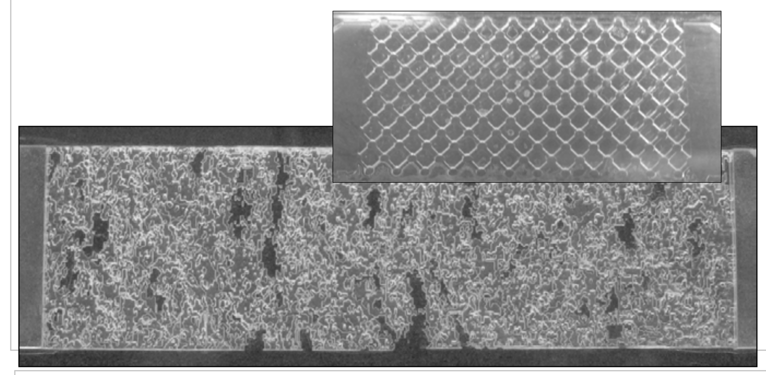
"Off-the-shelf" CFD software is being used to analyze everything from flow over airplanes to lab-on-a-chip designs. So, how accurately can two-phase immiscible flow be modeled flowing through some small-scale models of porous media?

We evaluate the capability of the CFD code FLUENT™ to model immiscible flow in micro-scale, bench-top stereolithography models. By comparing the flow results to experimental models we show that accurate 3D modeling is possible.

Materials and methods

Numerical – FLUENT 6.3, parallelization, and the Volume of Fluid method.

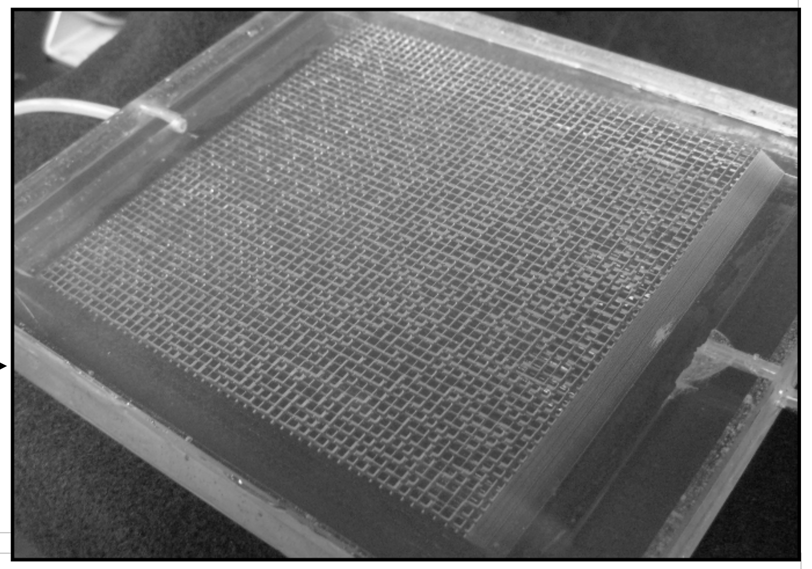
Experimental – Stereolithography models. Created from CAD drawings; same geometry used in models.



◀ Lattice on a microscope slide

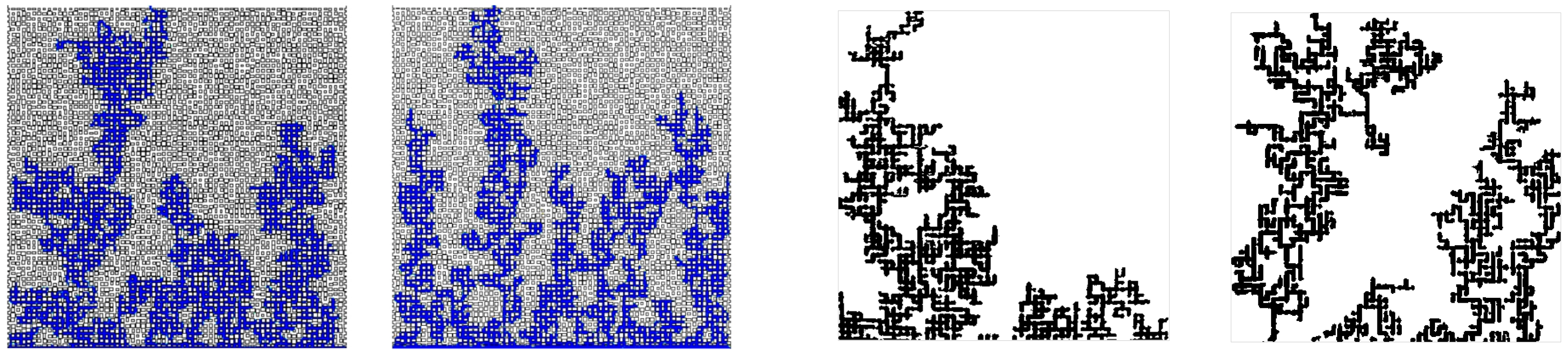
Square network, 10cm by 10cm ▶

◀ CT-Scanned rock fracture

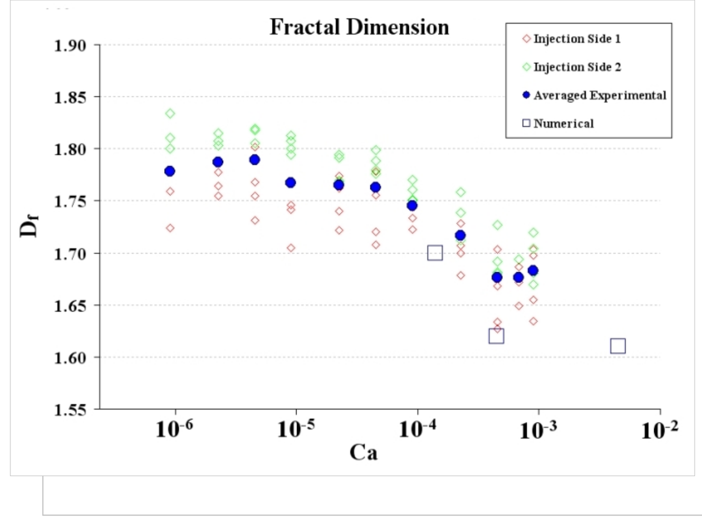


Modeling two-dimensional flow in micro-models

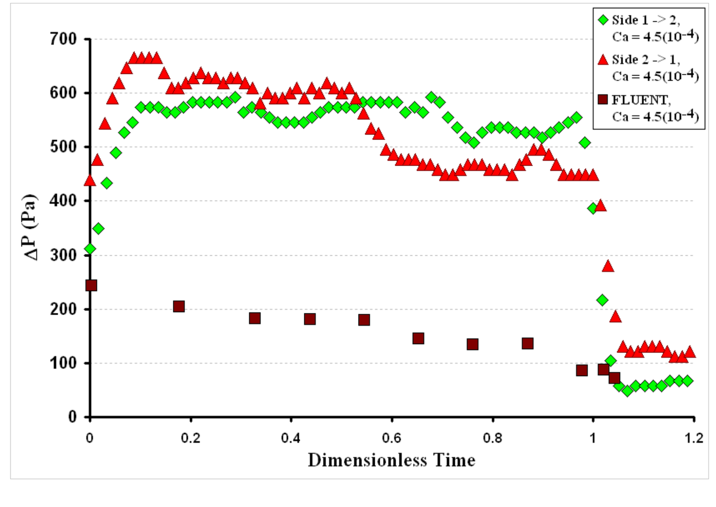
$$Ca = U\frac{\mu}{\sigma\cos\theta}$$



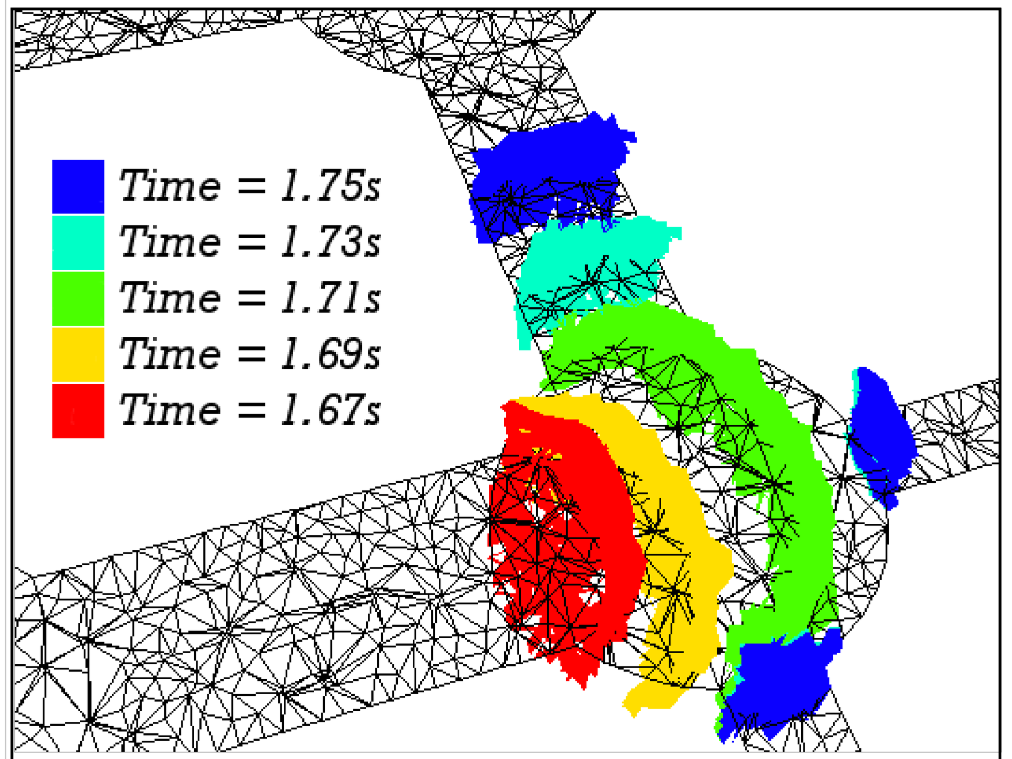
Ca = 4.5(10^{-4}) Ca = 4.5(10^{-5}) Ca = 9(10^{-8}) Ca = 4.5(10^{-4})



- Good match between experiments and 2D simulated fractal dimension (i.e. flow patterns) and saturation
- Poor match with the amount of time until breakthrough and pressure difference across the model

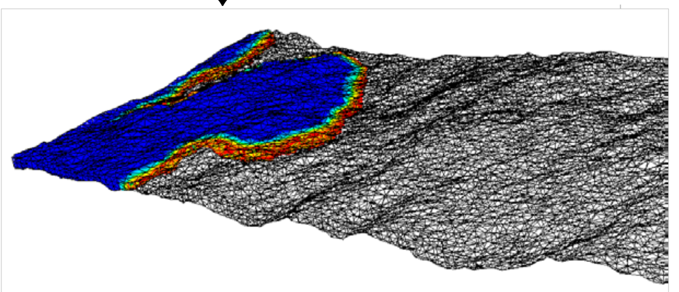


Modeling three-dimensional flow in micro-models

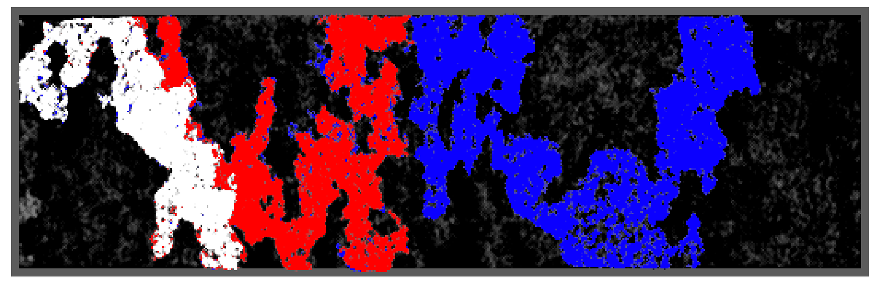


Air-water interface entering a lattice-cell pore during a simulation.

↓ Numerical rock fracture

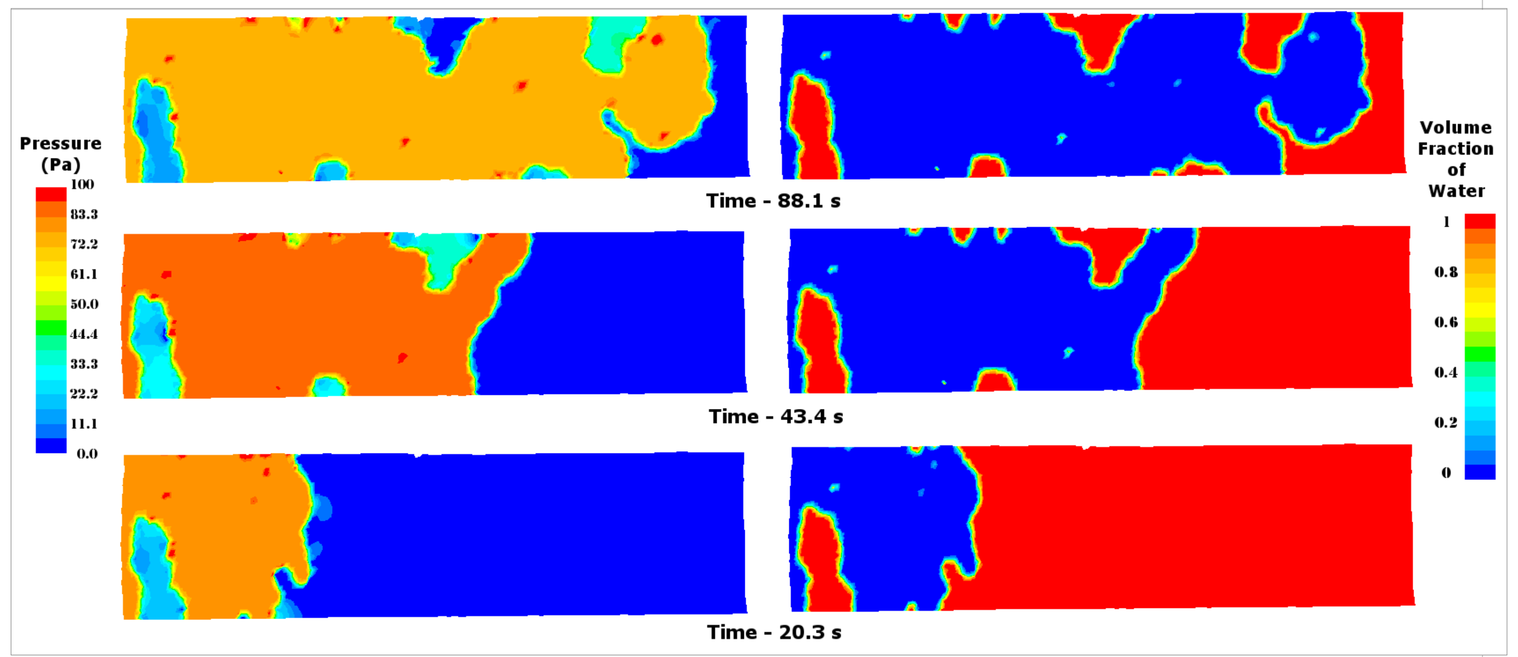


- 3D FLUENT models of air injected into water filled lattice and fracture models.
- Same lattice geometry and slightly different fracture geometry, due to geometric smoothing.
- Unsteady solutions, take up to months to reach completion using parallel processing.
- The interface evolution and pressure variation are readily available at very small time steps and throughout the computed domain.
- Good agreement with breakthrough times and a fair saturation match for the fracture models.
- Pressure still lower in 3D simulations, but improved compared to 2D models.



Time = 24.5 s, 45.5 s, and 79 s

Experiment Ca = 4.75 (10^{-6})



FLUENT Ca = 1.41 (10^{-5})

Conclusions

- 2D models of two-phase fluid motion in porous media capture many of the experimentally observed flow patterns, but the 'missing' third dimension drastically reduces the simulated pressure and time until breakthrough.
- 3D models of two-phase flow in the lattice network cell and the rock fracture are similar to the experimentally observed flows in the small-scale models. But these unsteady CFD simulations take a long time to complete.

References

Crandall, D., Ahmadi, G., Leonard, D., Ferer, M., and Smith, D.H., 2008, "A New Stereolithography Experimental Porous Flow Device", Rev. Sci. Instruments, **79**, 044501

Crandall, D., Ahmadi, G., and Smith, D.H., 2009, "Modeling of Gas-Liquid Flow through an Interconnected Channel Matrix", Proceedings of FEDSM2009, ASME 2009 Fluids Engineering Division Summer Meeting.

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