CFD-DEM Simulations of Proppant Particle Transport in Rough Walled Rock Fractures

Amir Mofakham, Goodarz Ahmadi
Department of Mechanical and Aeronautical Engineering
Clarkson University, Potsdam, NY

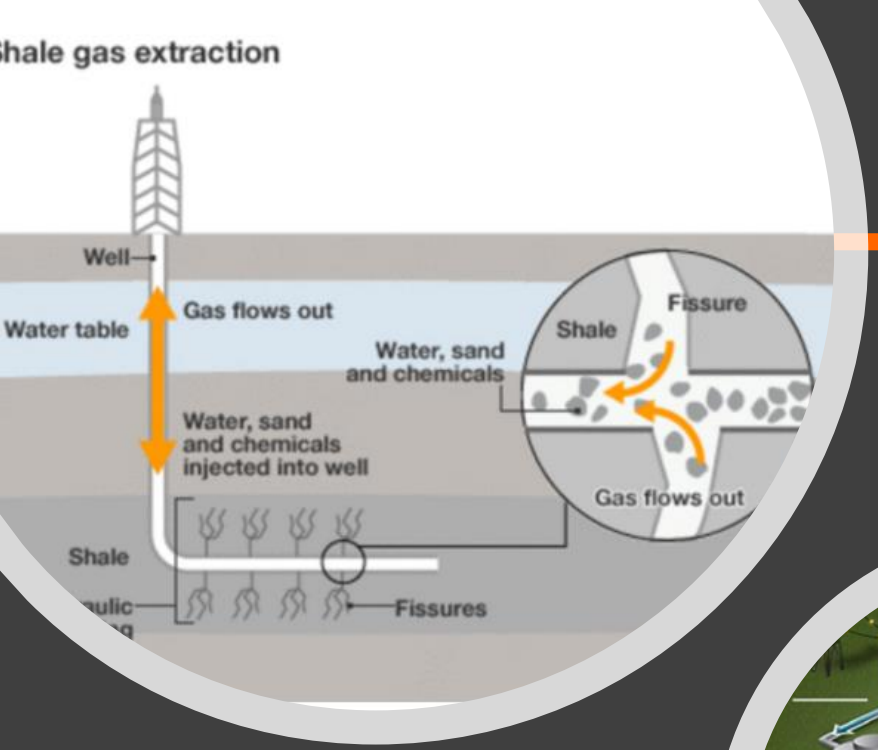
&

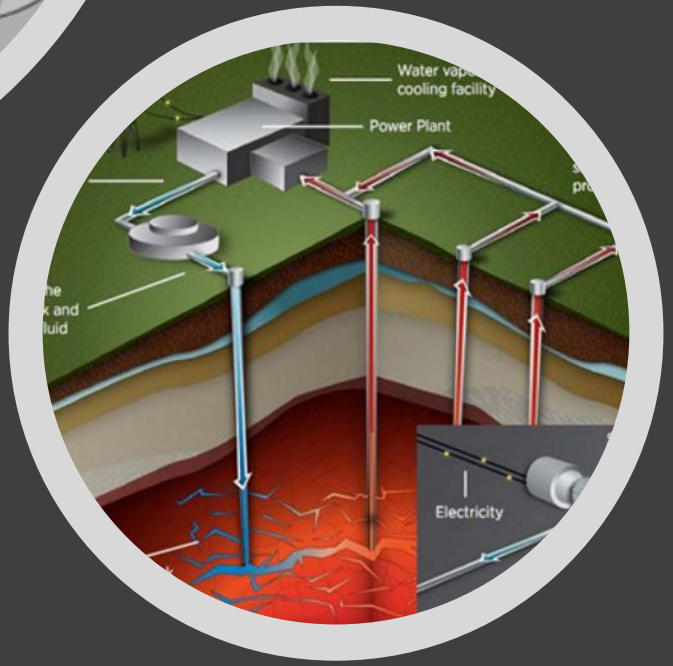
Dustin Crandall
National Energy Technology Laboratory
US Department of Energy, Morgantown, WV

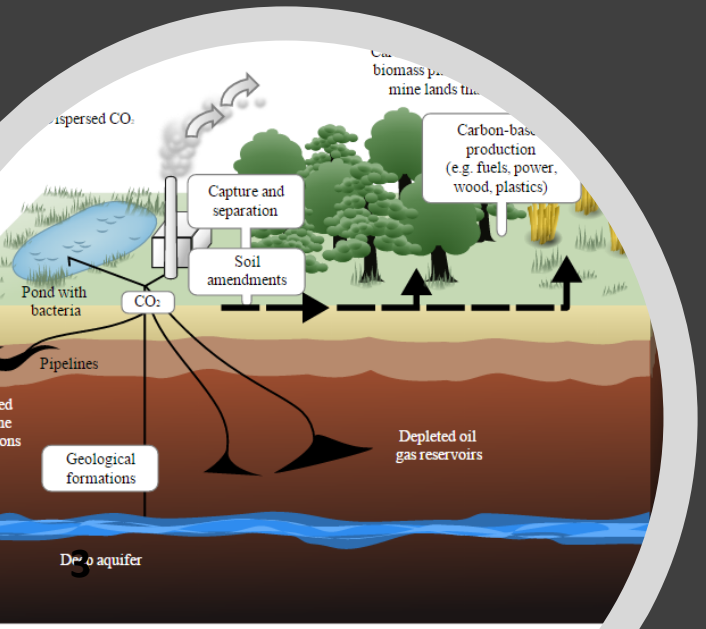
Aug, 2019

Outline

- Introduction
  - Fractures
  - Hydraulic Fracturing
- Numerical Model
  - CFDEM
    - Resolved
    - Unresolved
- Results
  - Idealized Fractures
  - Synthetic Fractures
- Conclusions and Future Works



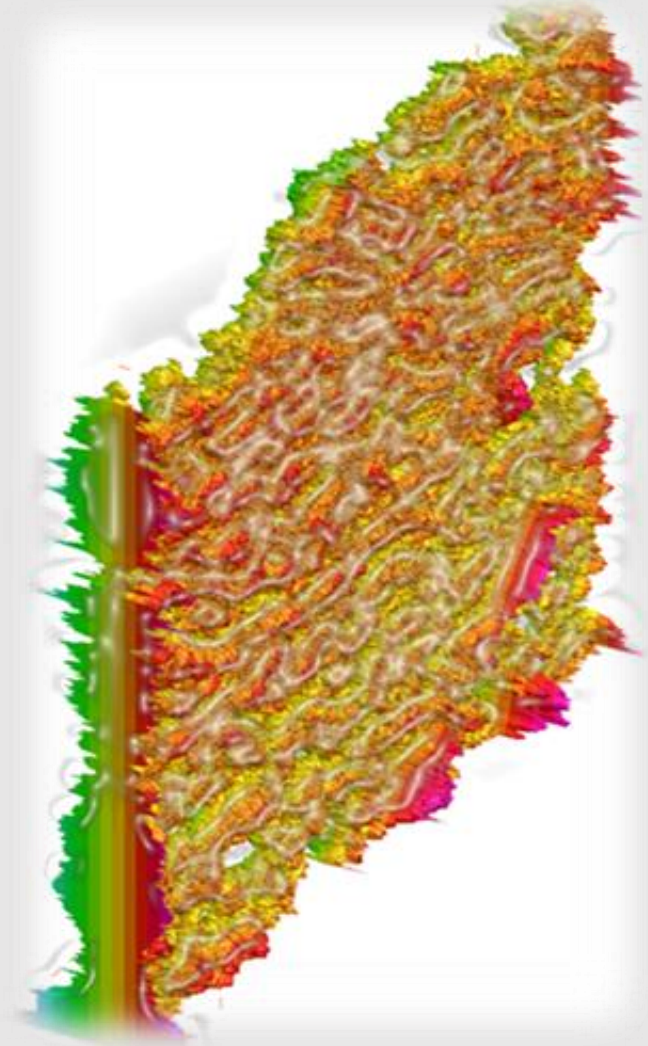




Introduction

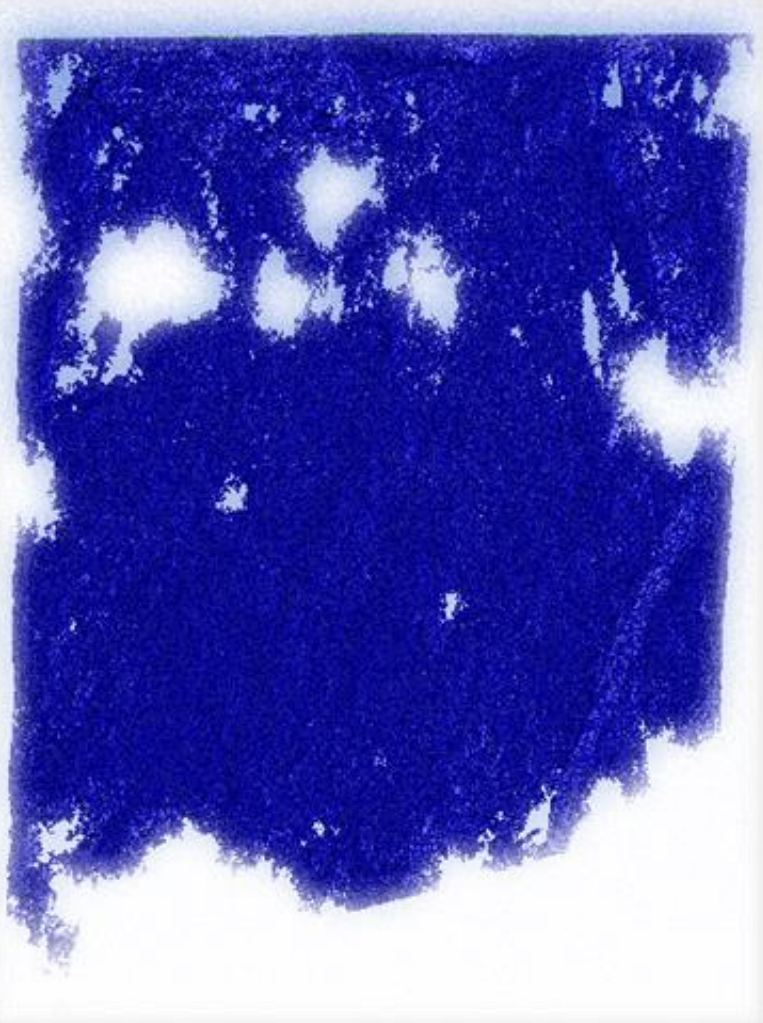
- Fractures are conduits in subsurface rocks
  - Unconventional oil and gas resources
  - Carbon sequestration reservoir
  - Enhanced geothermal system

Hydraulic Fracturing



https://www.marathonoil.com/

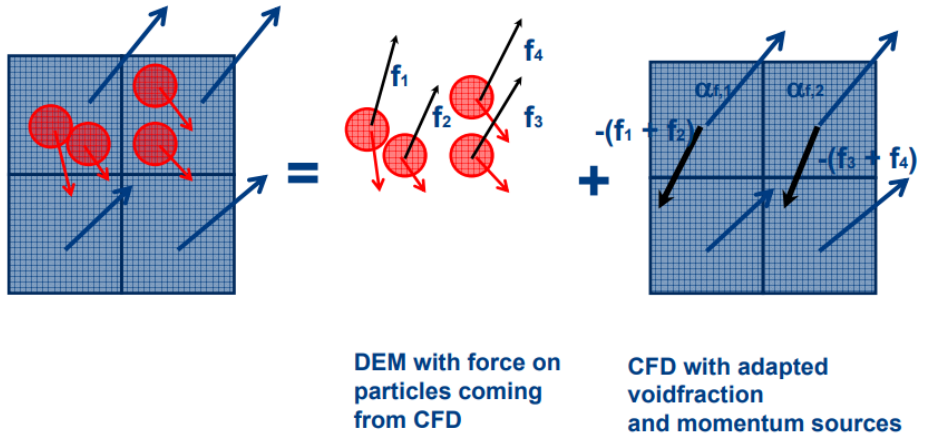
Numerical Section



CFDEM Code

- CFDEM = CFD + DEM
  - CFD
    - ✓ OpenFOAM = **Open** source **F**ield **O**peration **A**nd **M**anipulation
  - DEM
    - ✓ LIGGGHTS = **L**AMMPS **I**mproved **G**eneral **G**ranual and **G**ranual **H**eat **T**ransfer **S**imulations

Theoretical background:



- 4-way coupling
  - Unresolved
  - Resolved

Hager, A., Kloss, C., Pirker, S., Goniva, C.: Parallel Resolved Open Source CFD-DEM: Method, Validation and Application. The Journal of Computational Multiphase Flows **6**(1), 13-27 (2014)

Resolved & Unresolved

- Unresolved
  - Particles & Particles
  - Particles & Walls
  - Fluid on Particles
  - Particles on Fluid → Drag force

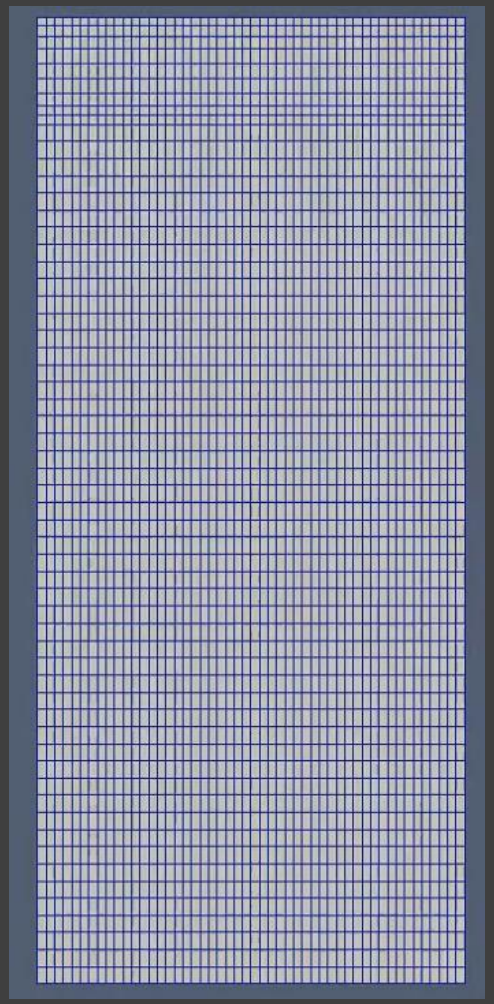
✓ Less accurate
✓ Less expensive
✓ A large number of particles

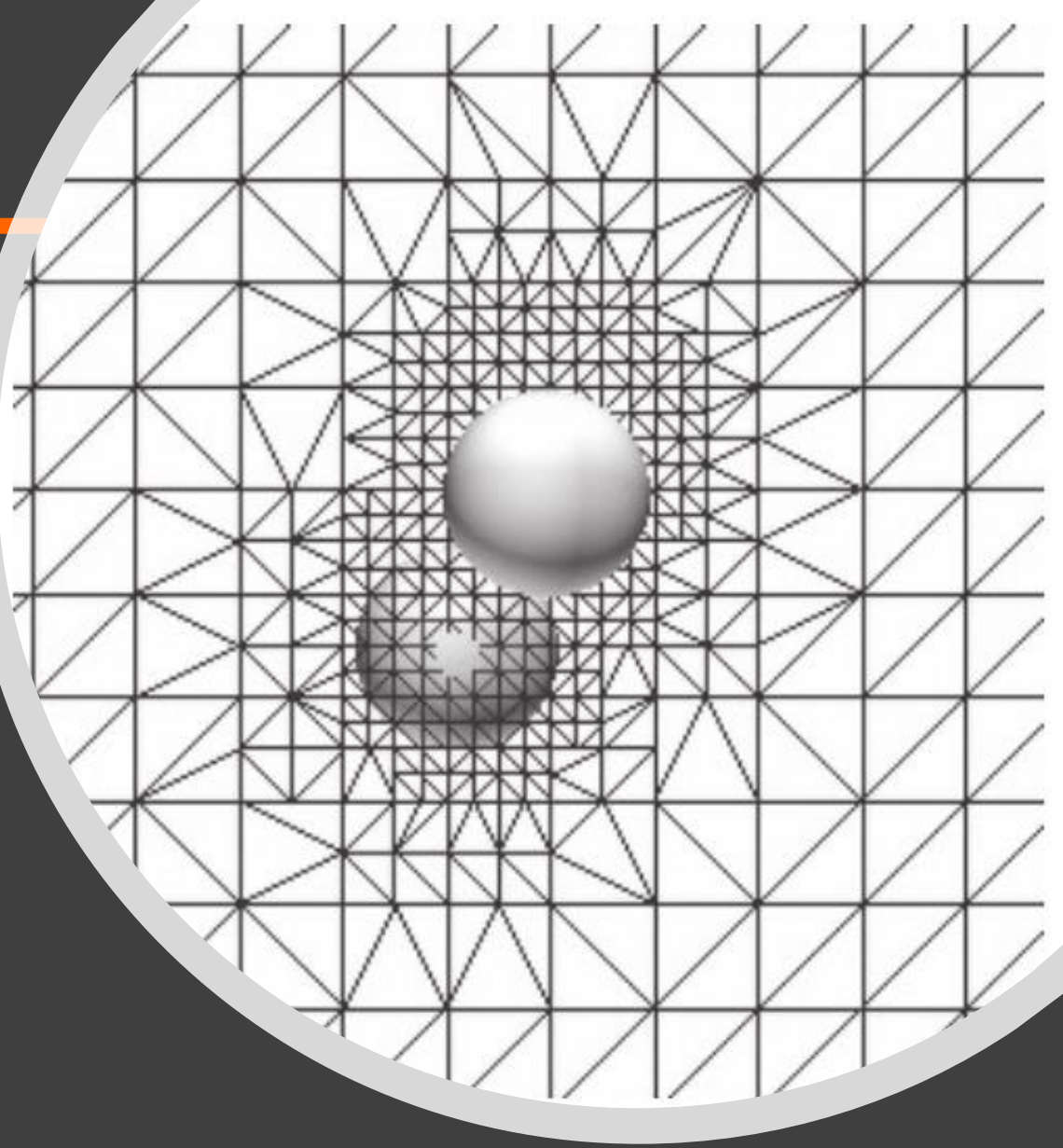
- Resolved
  - Particles & Particles
  - Particles & Walls
  - Fluid on Particles
  - Particles on Fluid
    1. Fluid velocity excluding particles is evaluated.
    2. Particle velocities are calculated.
    3. Fluid velocity at particles' location is updated.
    4. The continuity equation is recalculated.

✓ More accurate
✓ Few, large objects
✓ Grids smaller than particles

Hager, A., Kloss, C., Pirker, S., Goniva, C.: Parallel Resolved Open Source CFD-DEM: Method, Validation and Application. The Journal of Computational Multiphase Flows **6**(1), 13-27 (2014)

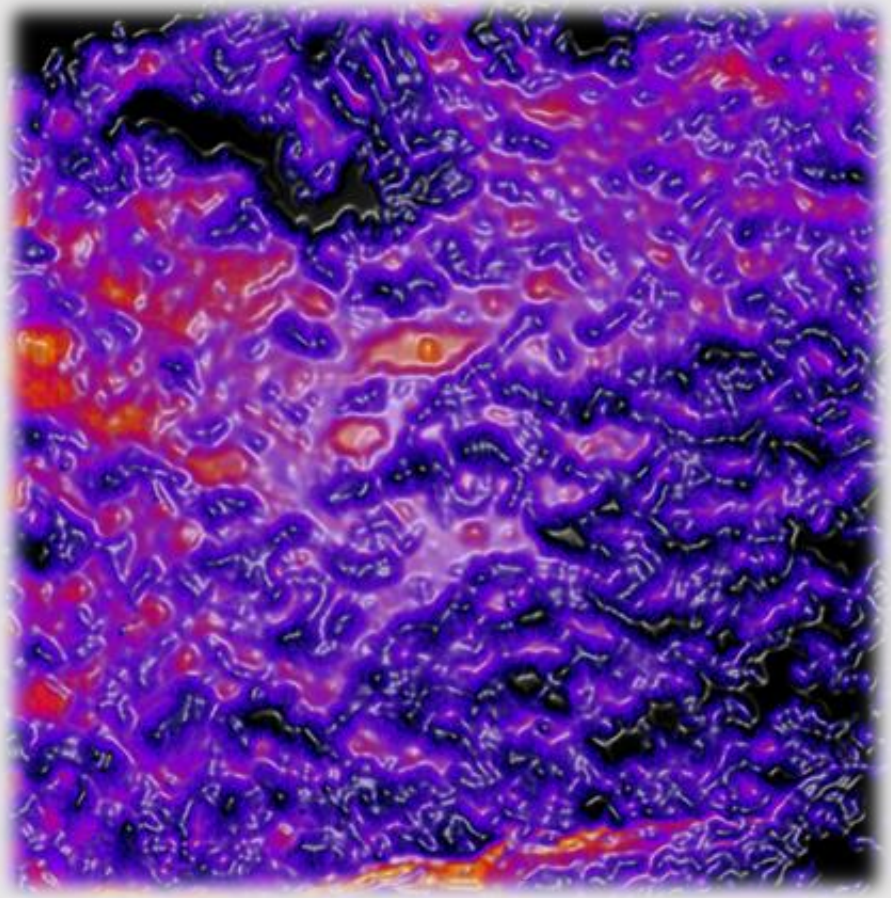
Dynamic Local Mesh Refinement



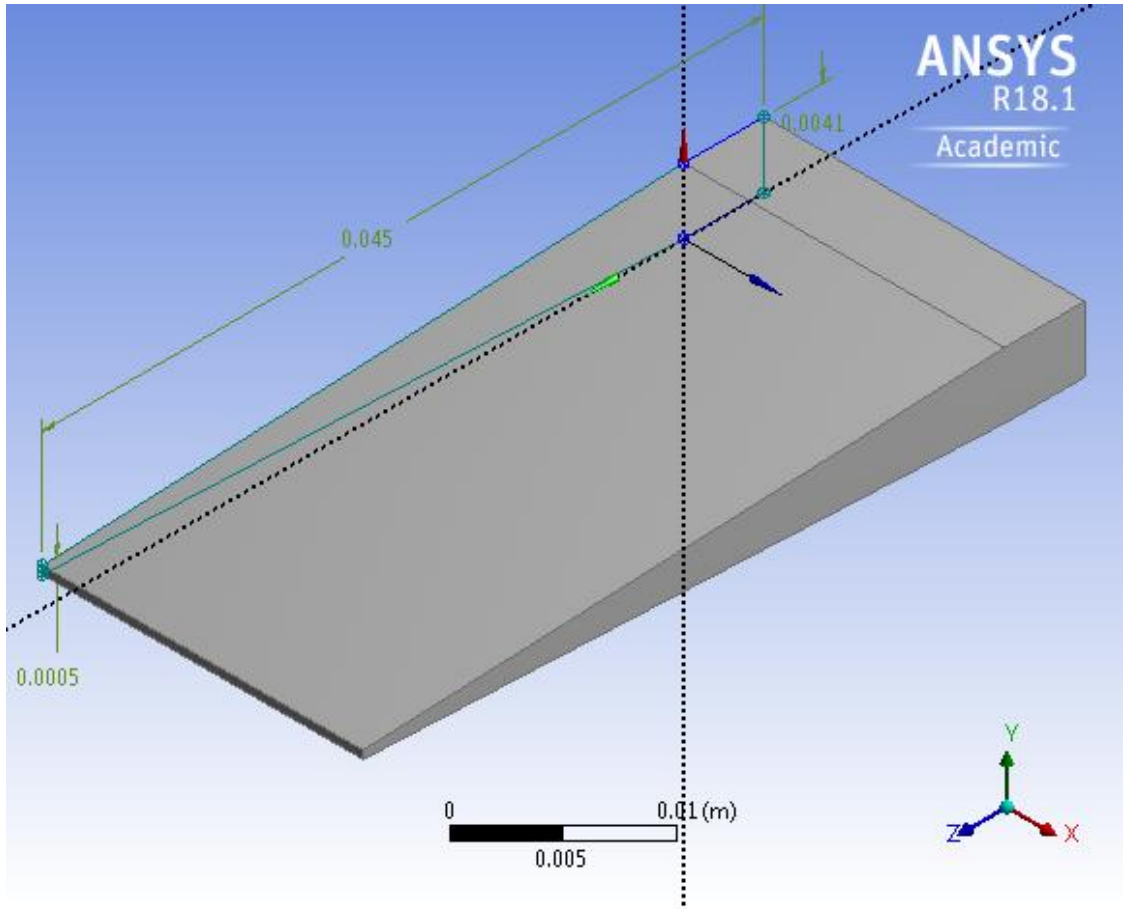


Hager, A., Kloss, C., Pirker, S., Goniva, C.: Parallel Resolved Open Source CFD-DEM: Method, Validation and Application. The Journal of Computational Multiphase Flows **6**(1), 13-27 (2014)

Results



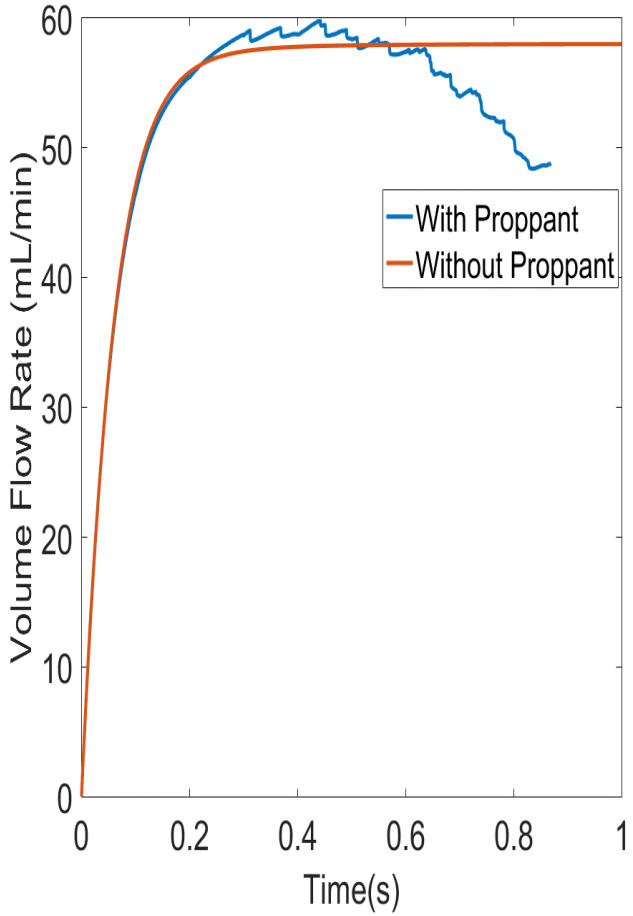
Idealized Fractures



- 4-way coupling
  - Unresolved
  - Resolved ✓

Idealized Fractures

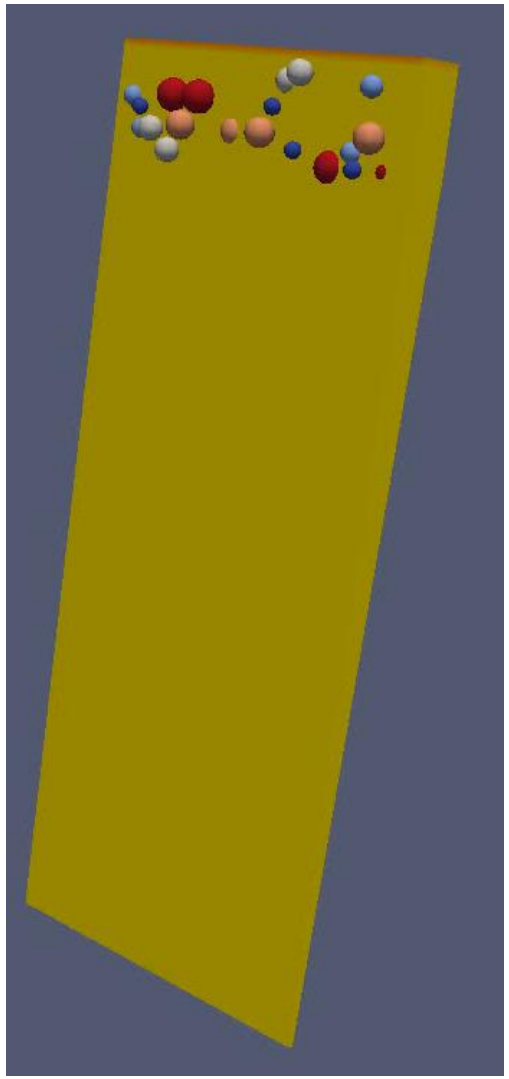
Fluid Pathlines



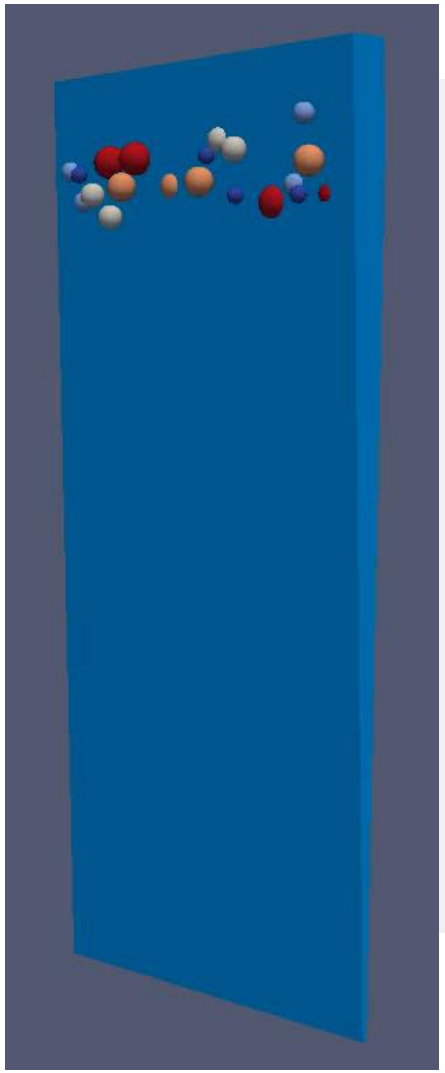
Z-Velocity Contours

- **Drafting**
- **Kissing**
- **Tumbling**

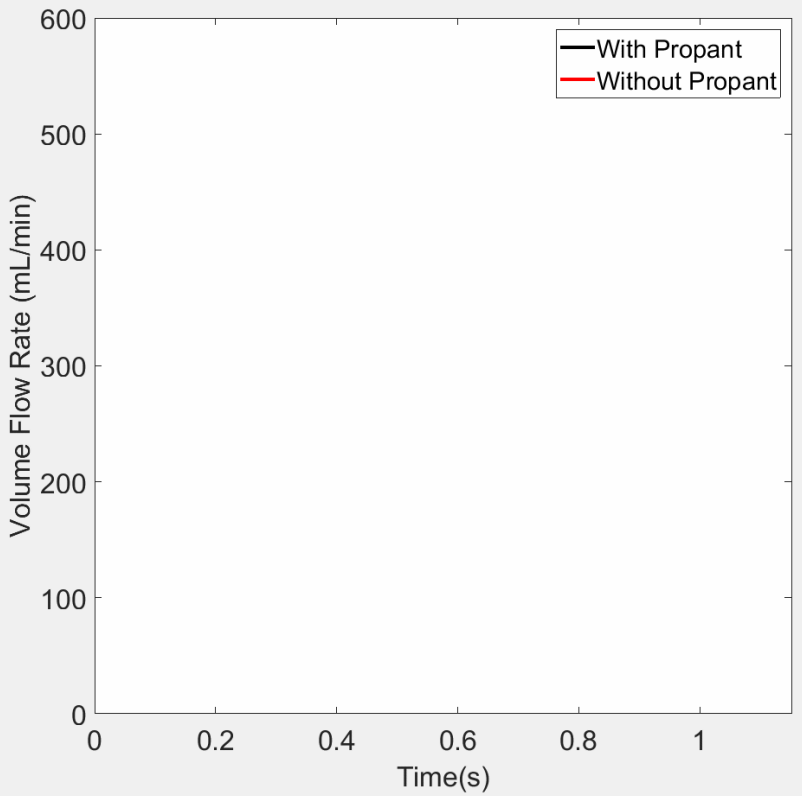
Idealized Fractures



Pressure Contours

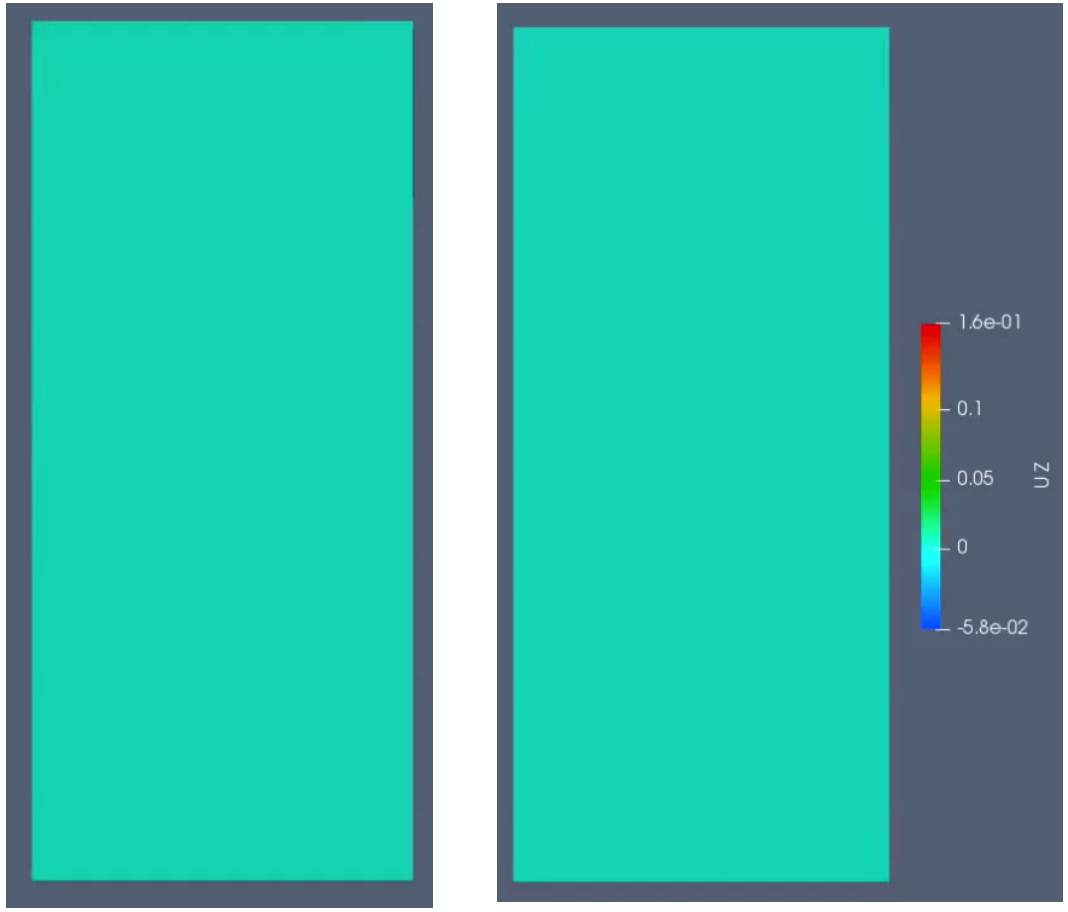


Z-Velocity Contours



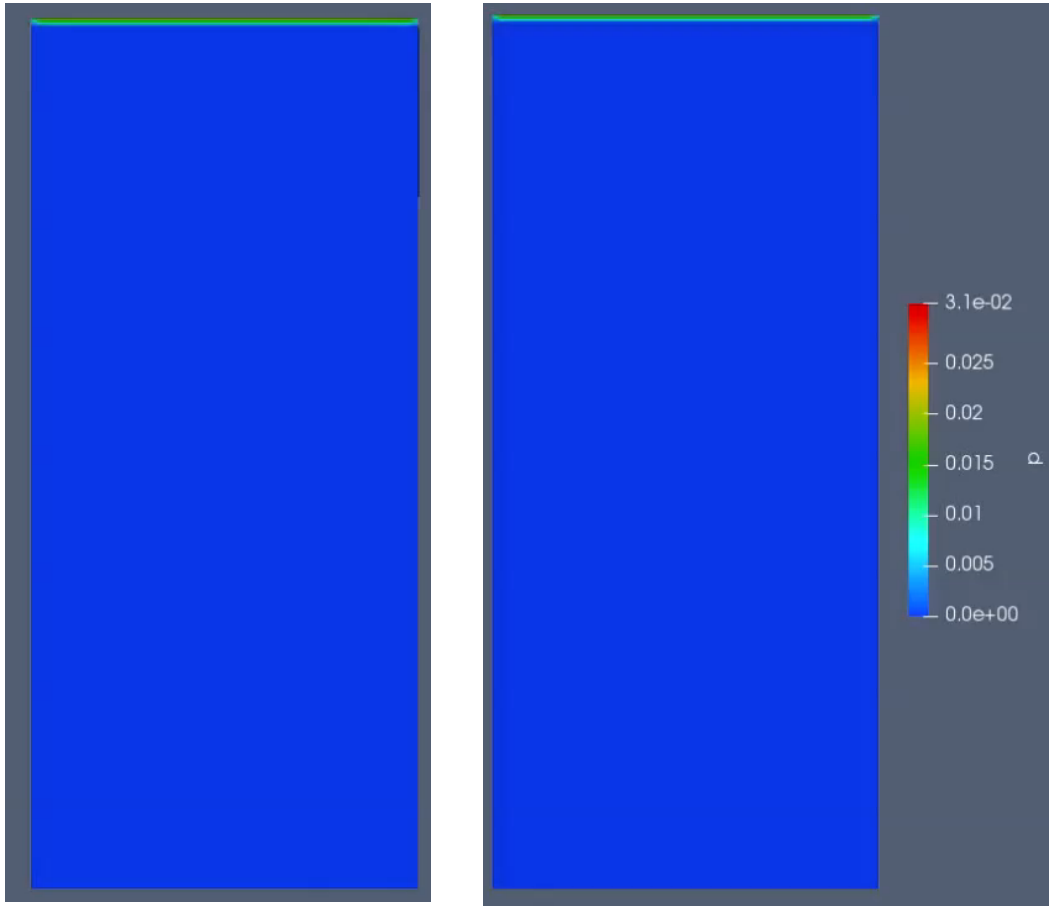
Comparison
Fully-Resolved & Unresolved

Velocity Contours



Unresolved **Fully Resolved**

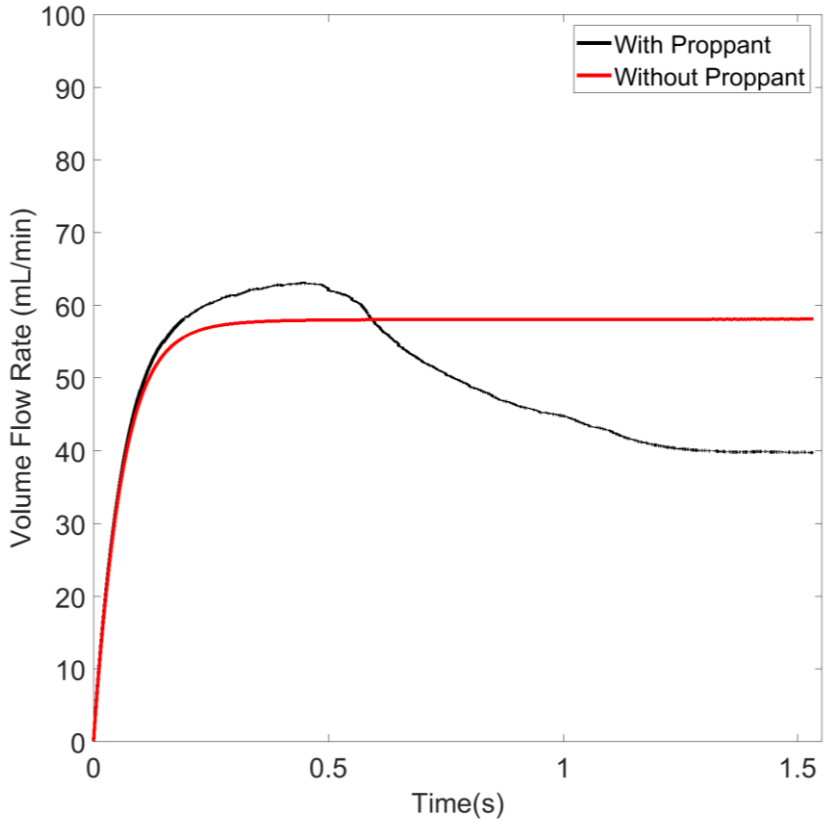
Pressure Contours



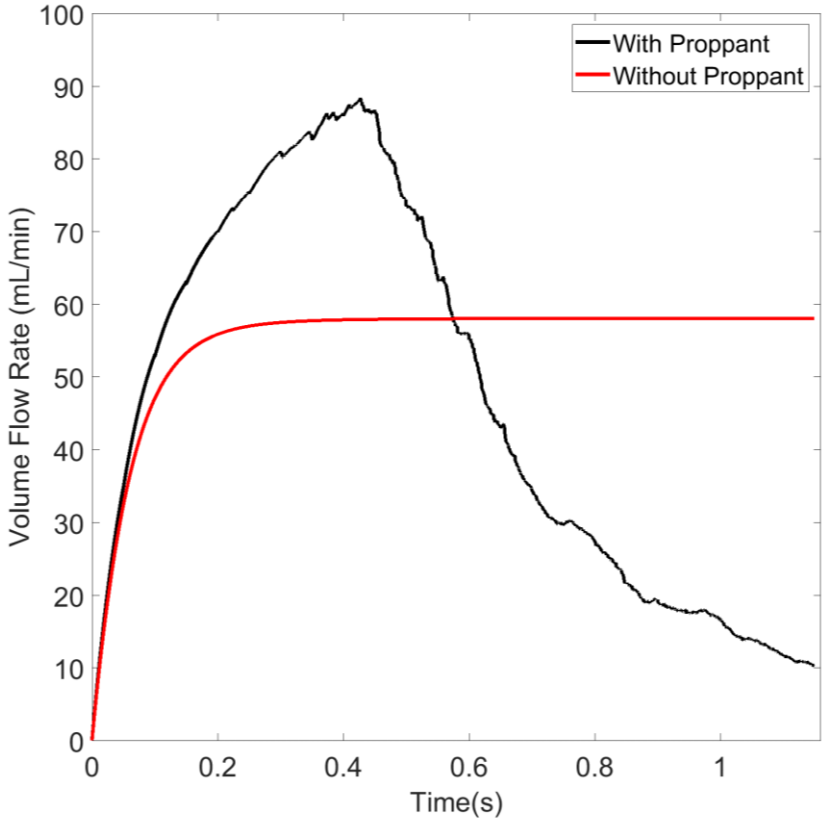
Unresolved **Fully Resolved**

Comparison
Fully-Resolved & Unresolved

	Unresolved	Fully Resolved
Computational Time	1 hour	24 days and 10 hours
Processors	two Xeon E5-2640 v3 CPU	

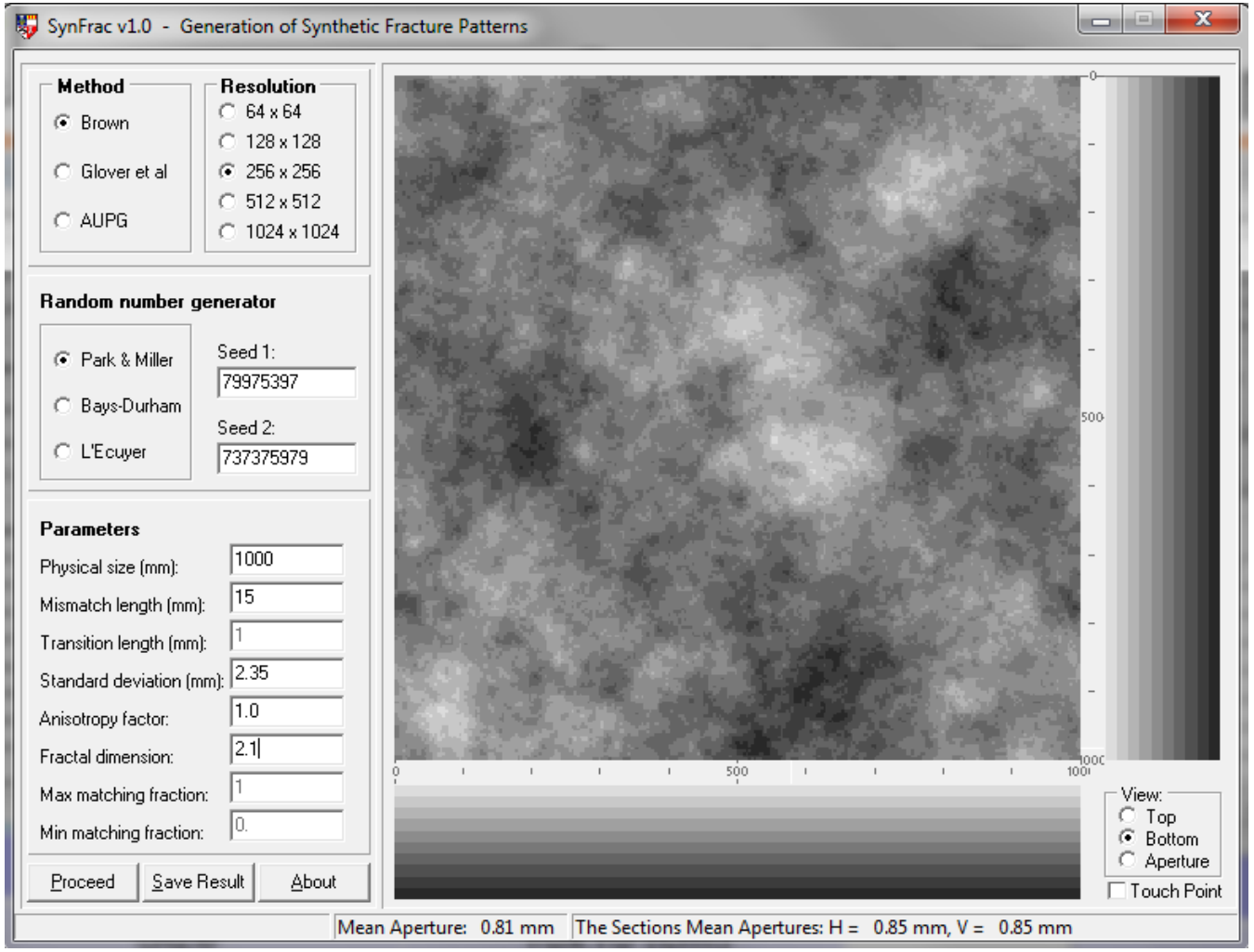


Unresolved



Fully Resolved

Synthetic Fracture

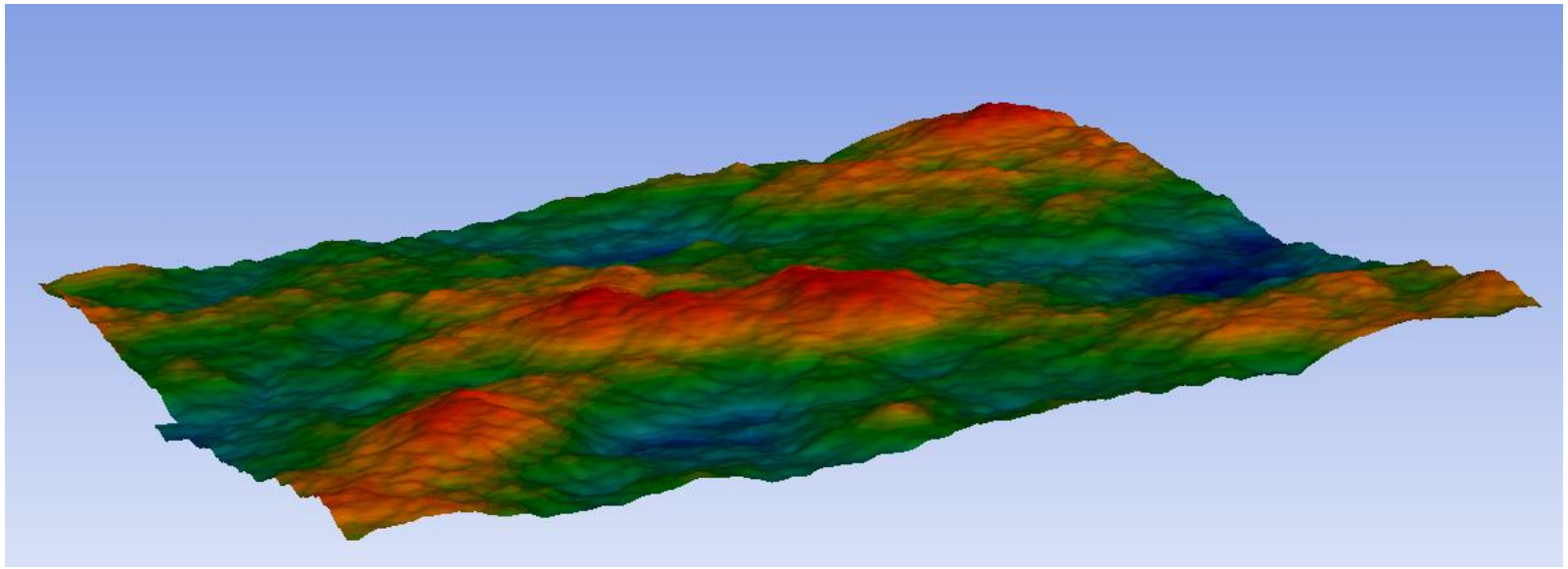


Fractures Characteristics	
Small Size	10x10 (cm)
Large Size	1x1 (m)
Mean Aperture	0.8 (mm)
Standard Deviation	1 (mm)
Fractal Dimension	2.1

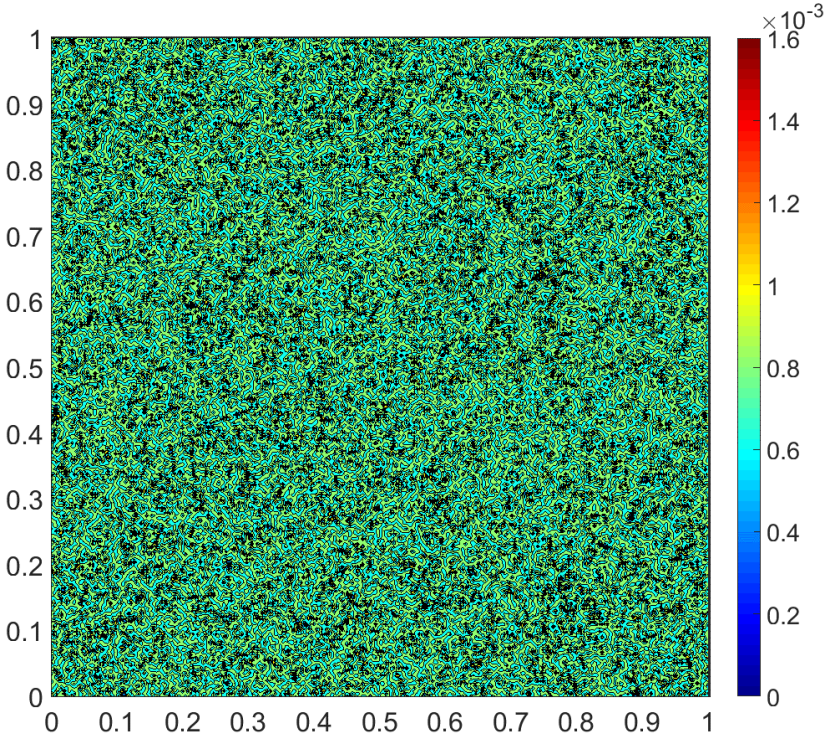
- 4-way coupling
  - Unresolved ✓
  - Resolved

Isakov, E., Ogilvie, S.R., Taylor, C.W., Glover, P.W.: Fluid flow through rough fractures in rocks I: high resolution aperture determinations. Earth and Planetary Science Letters **191**(3-4), 267-282

Geometry of the large size

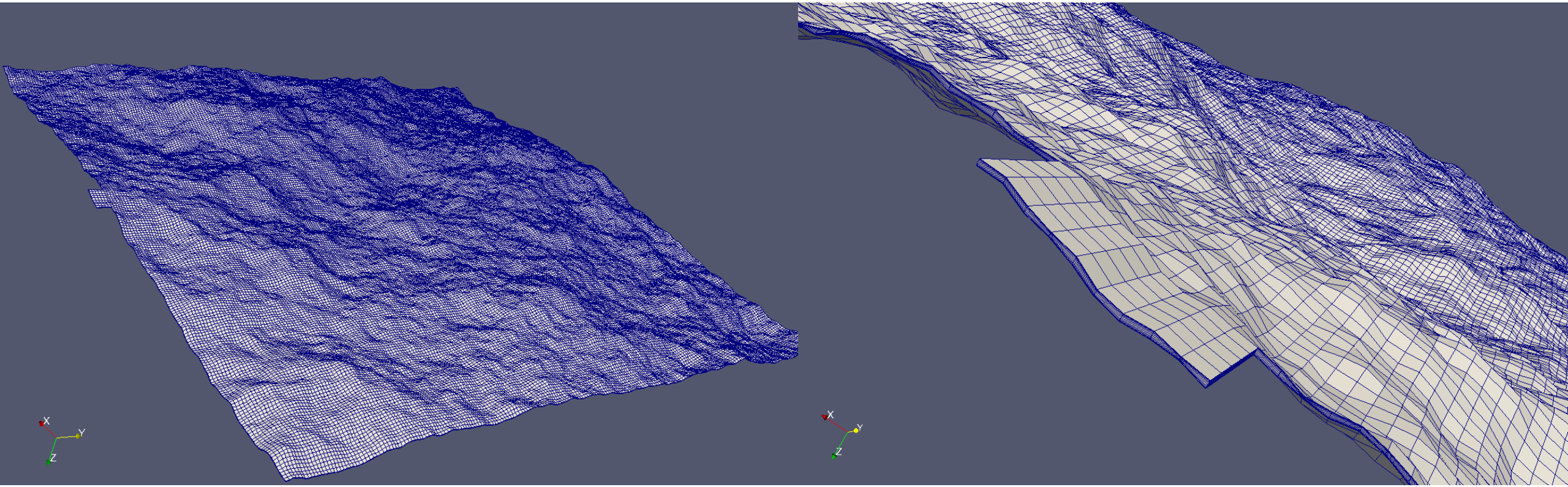


Aperture Wall



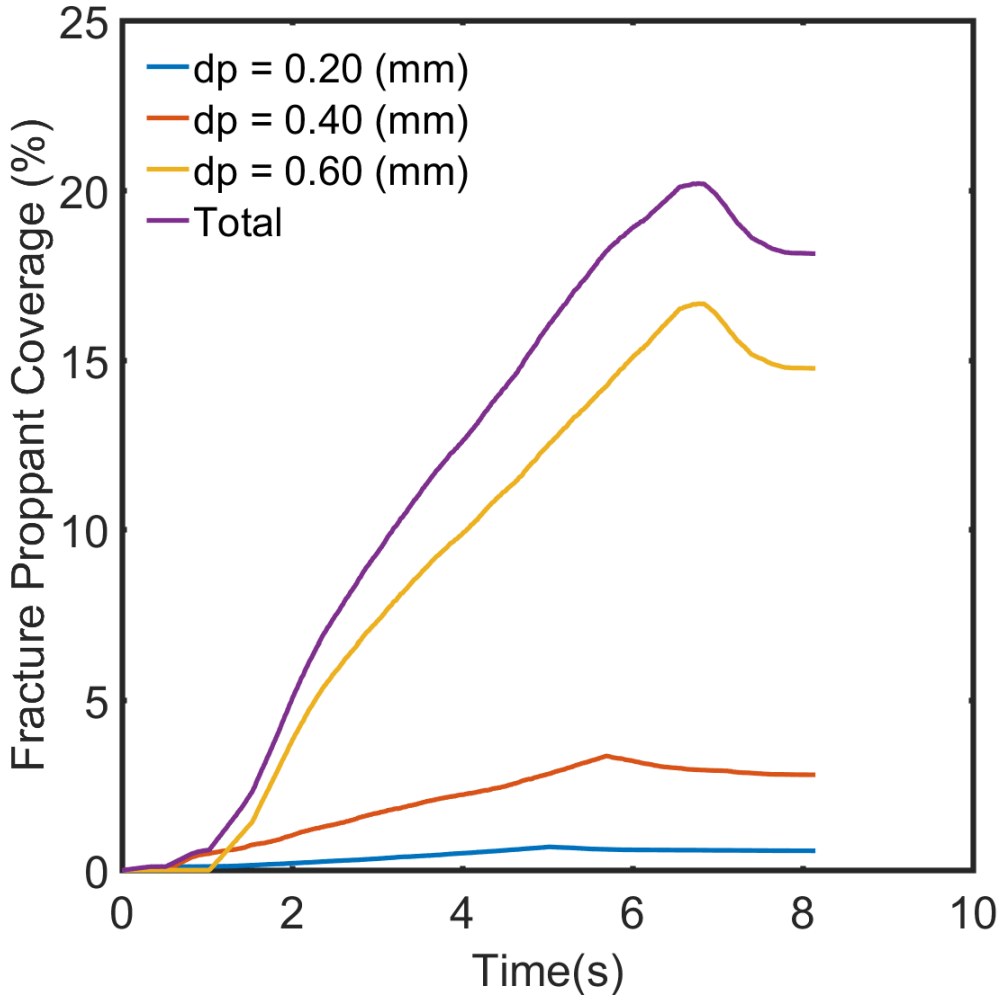
Aperture Map

Gridding and Geometry of the Fracture



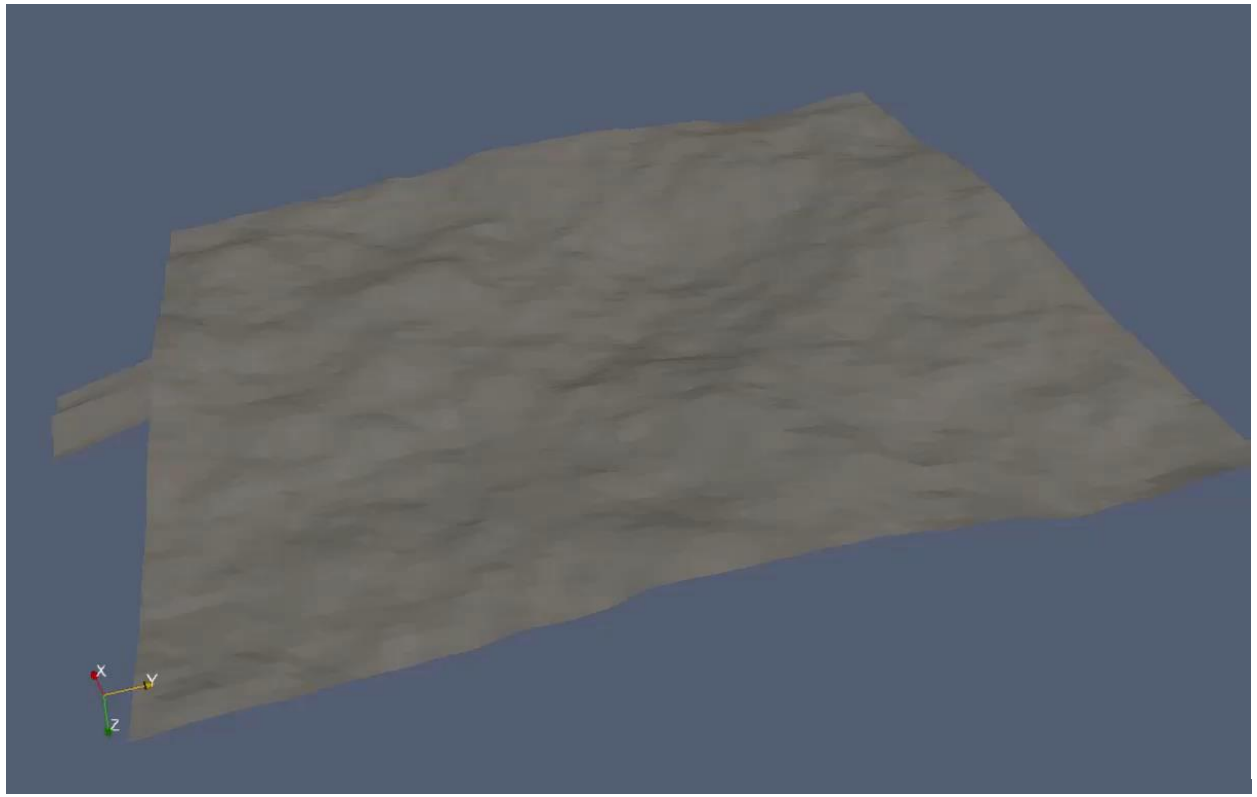
Small Fractures

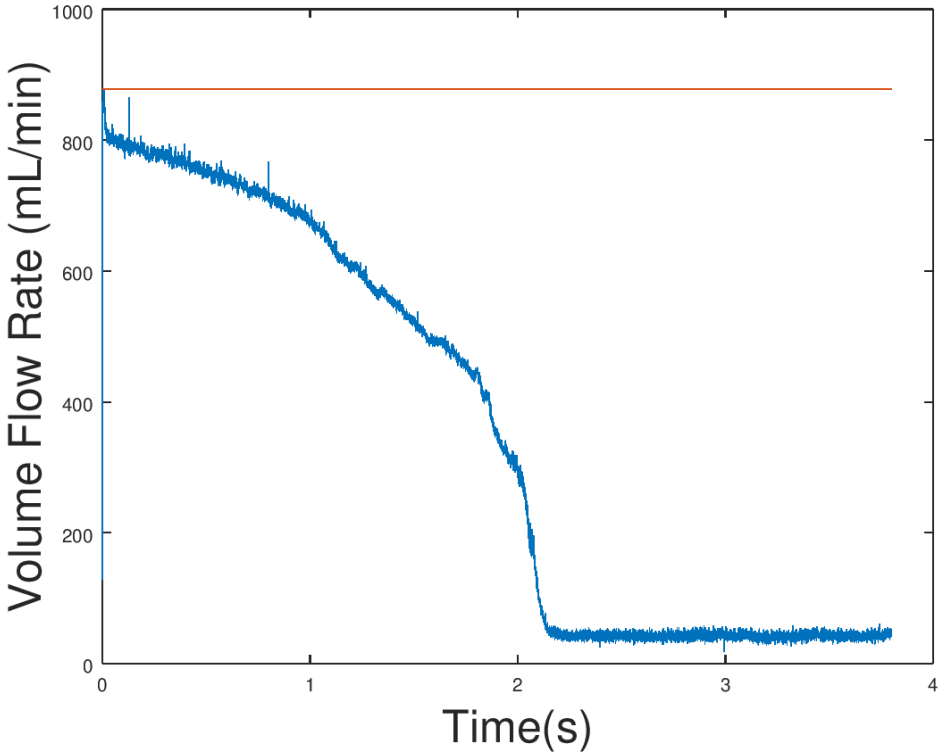
Proppant Diameter (mm)	Injection Rate (1/s)
0.2	1000
0.4	1000
0.6	1000



Clogged Small Fractures

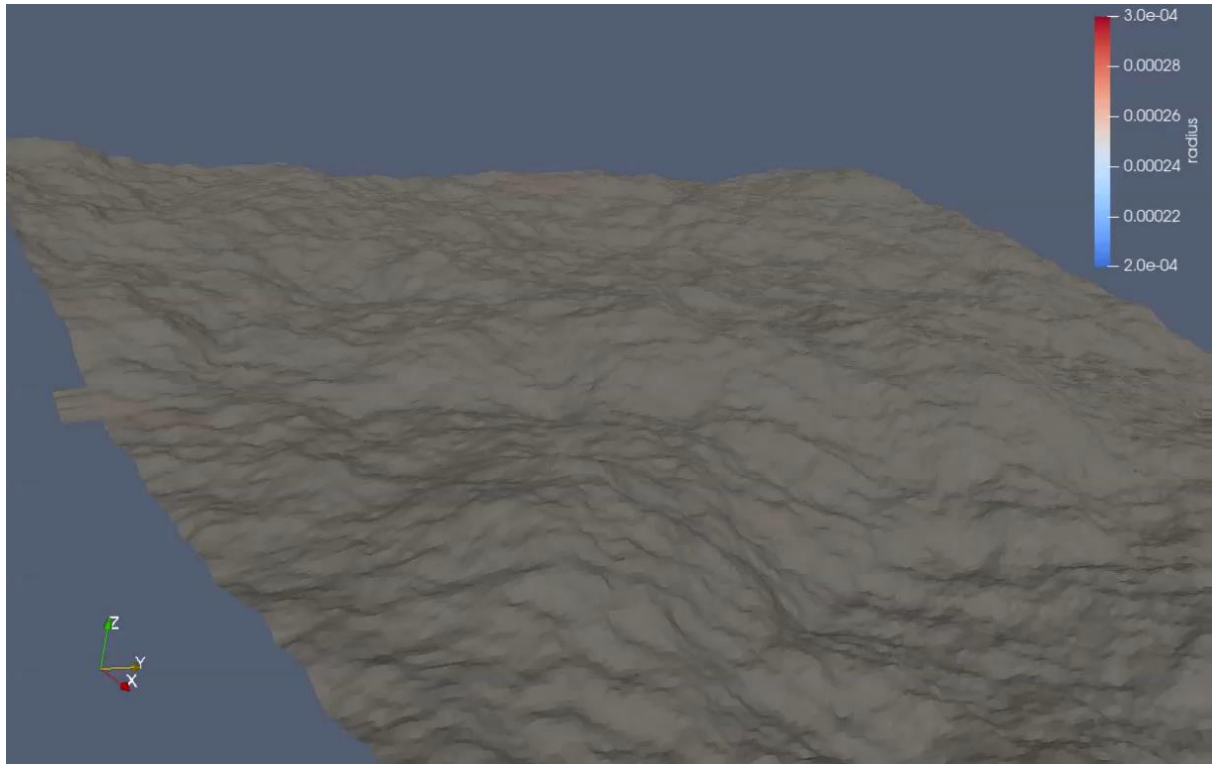
Proppant Diameter (mm)	Injection Rate (number of proppant/Time) (1/s)
0.5	10,000

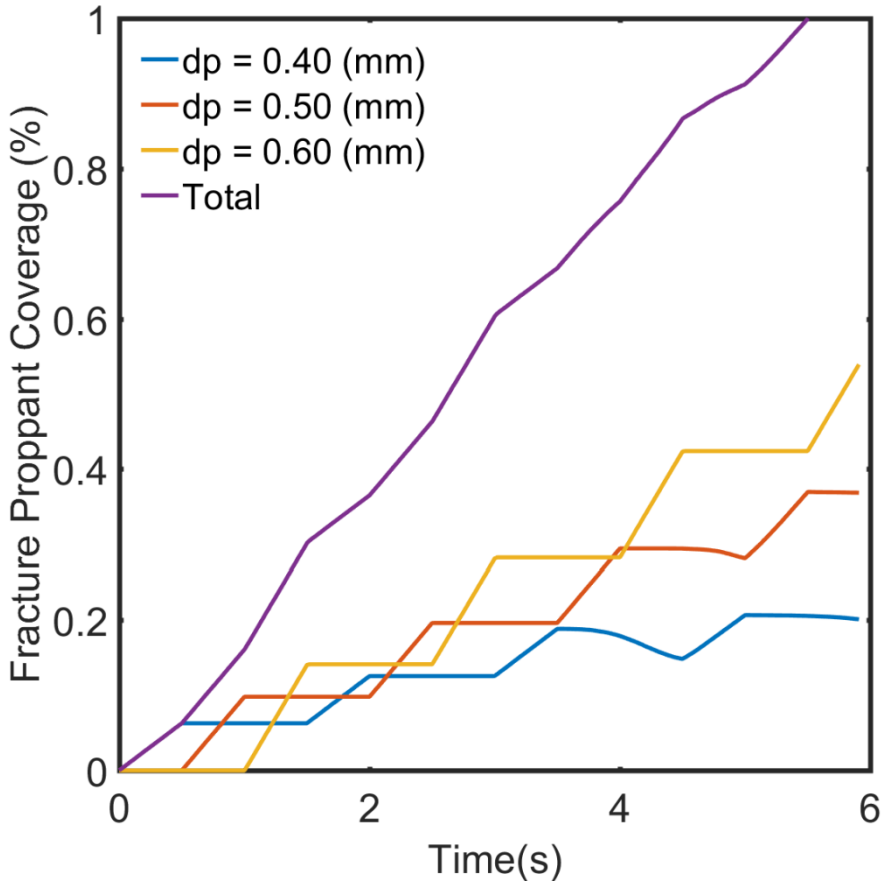




Large Fractures

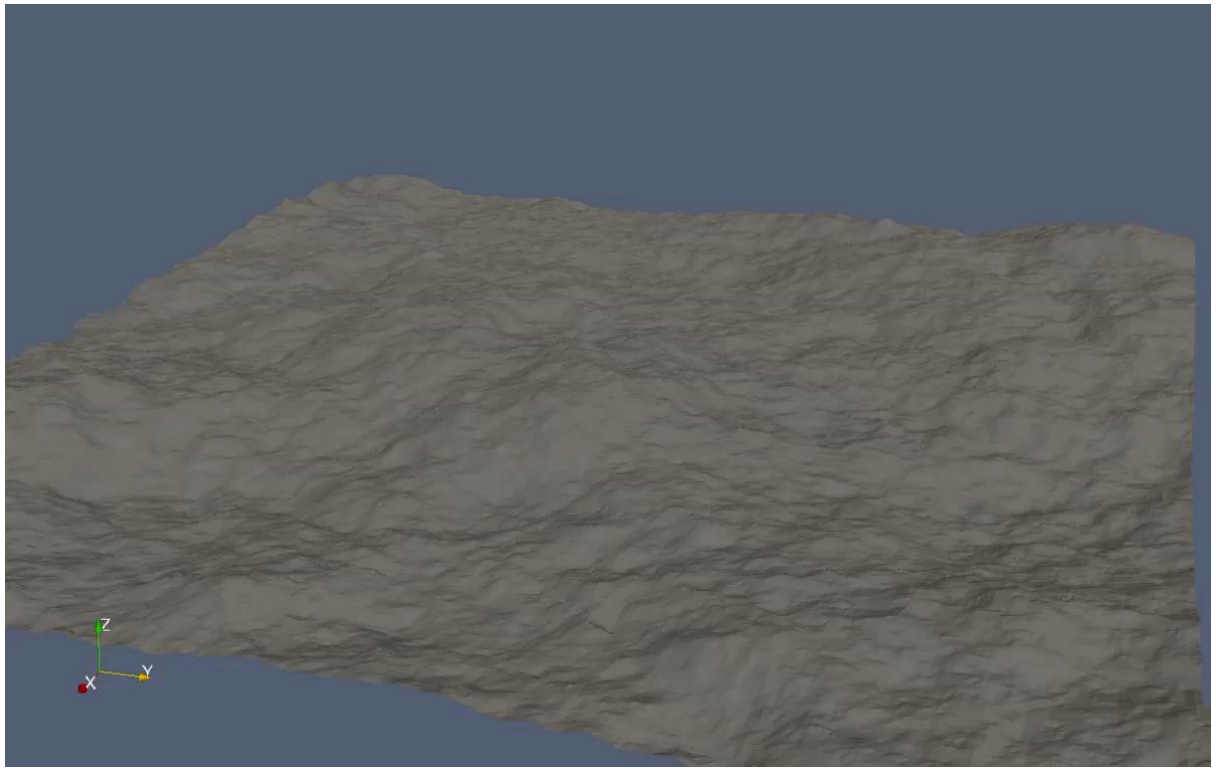
Proppant Diameter (mm)	0.4, 0.5, 0.6

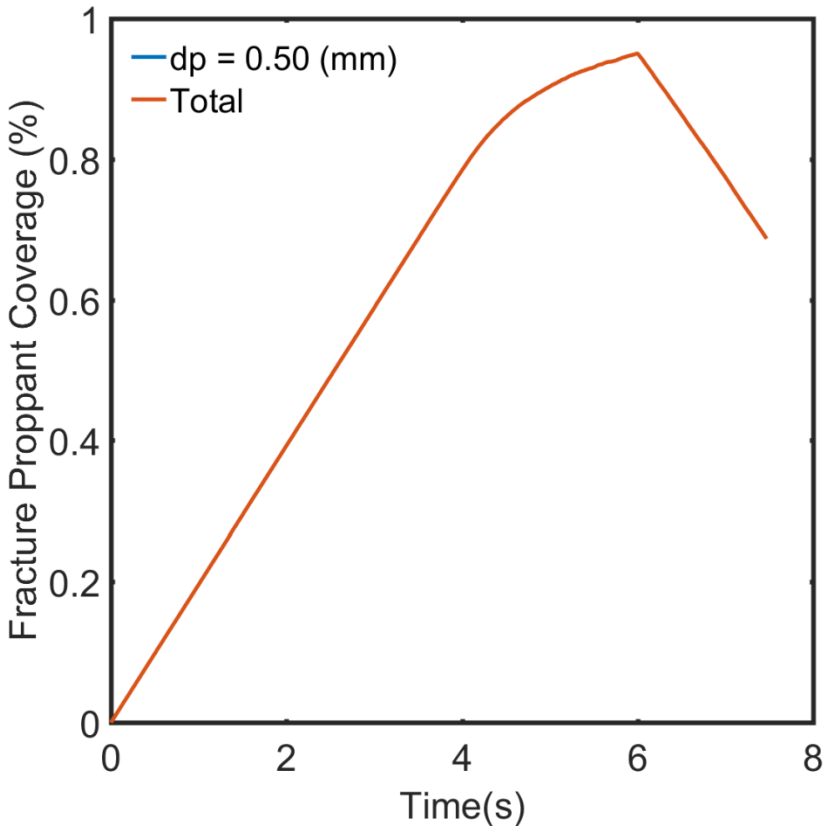




Large Fractures

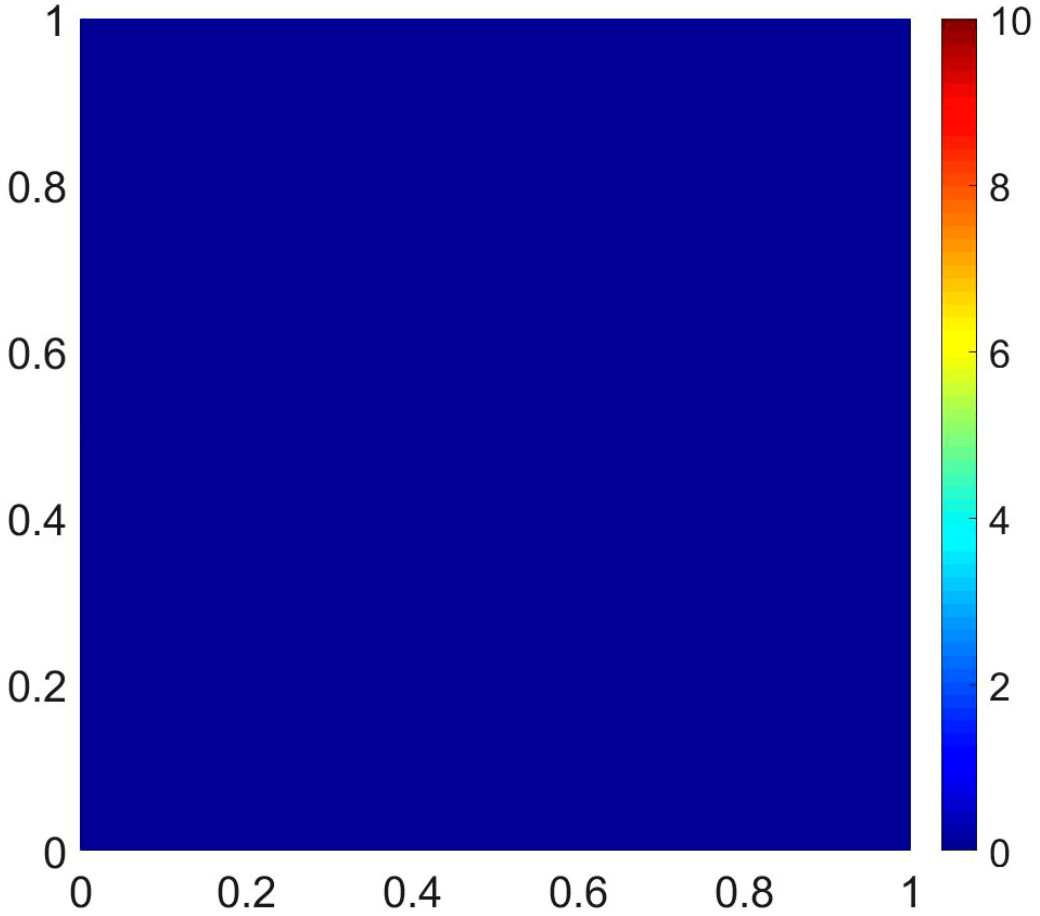
Proppant Diameter (mm)	0.5

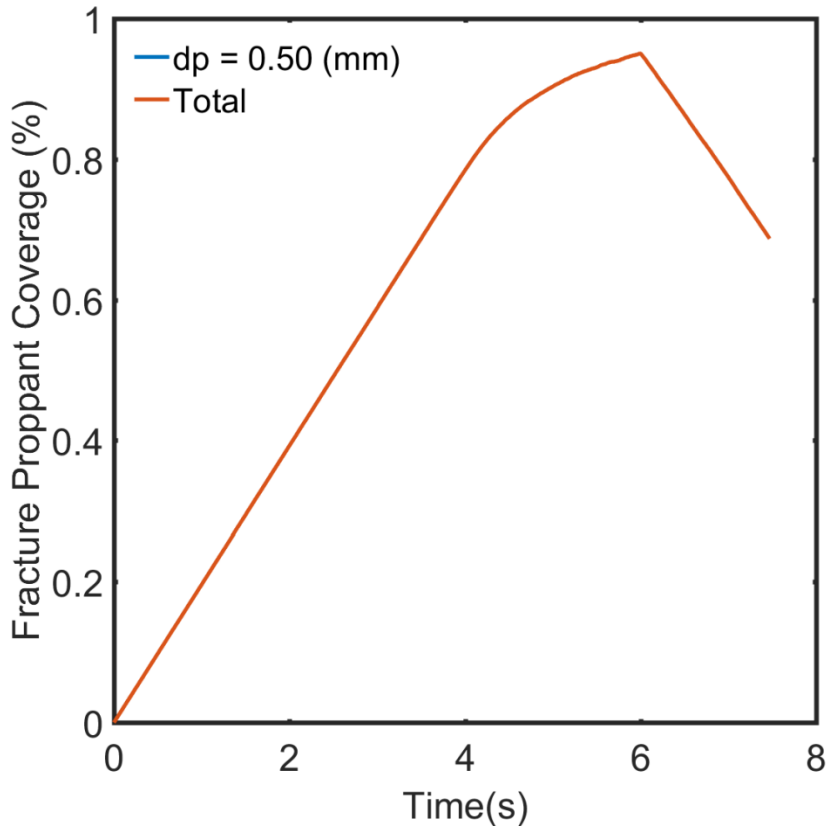




Large Fractures

Proppant Diameter (mm)	0.5



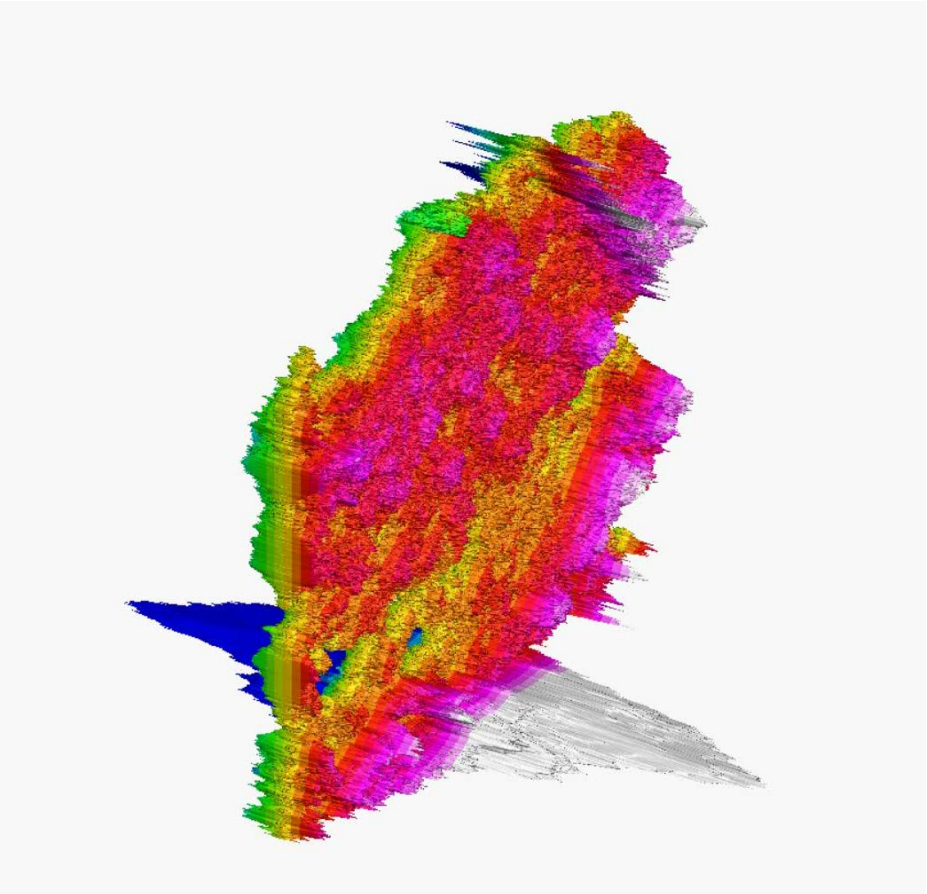


Conclusions

- The model is capable evaluating flow blockage by proppant capture in the fracture.
- Synthetic fracture provides a good approximation for real fractures.
- Proppant with a diameter of 0.6 mm gives a good coverage.

Future Works

- Study the effects of the flow rate on proppant coverage.
- Use the actual geometry and compare the results.
- Model the chemical reactions in fractures.
- Include ellipsoidal particles to model sensors
- Estimate backflow after fracking and removing hydraulic pressure



thank you!