Numerical Simulation of Rock Fracture Coverage with Proppants during Hydraulic Fracturing

Farid Rousta[1], Amir Mofakham[1], Dustin Crandall[2], Goodarz Ahmadi[1]

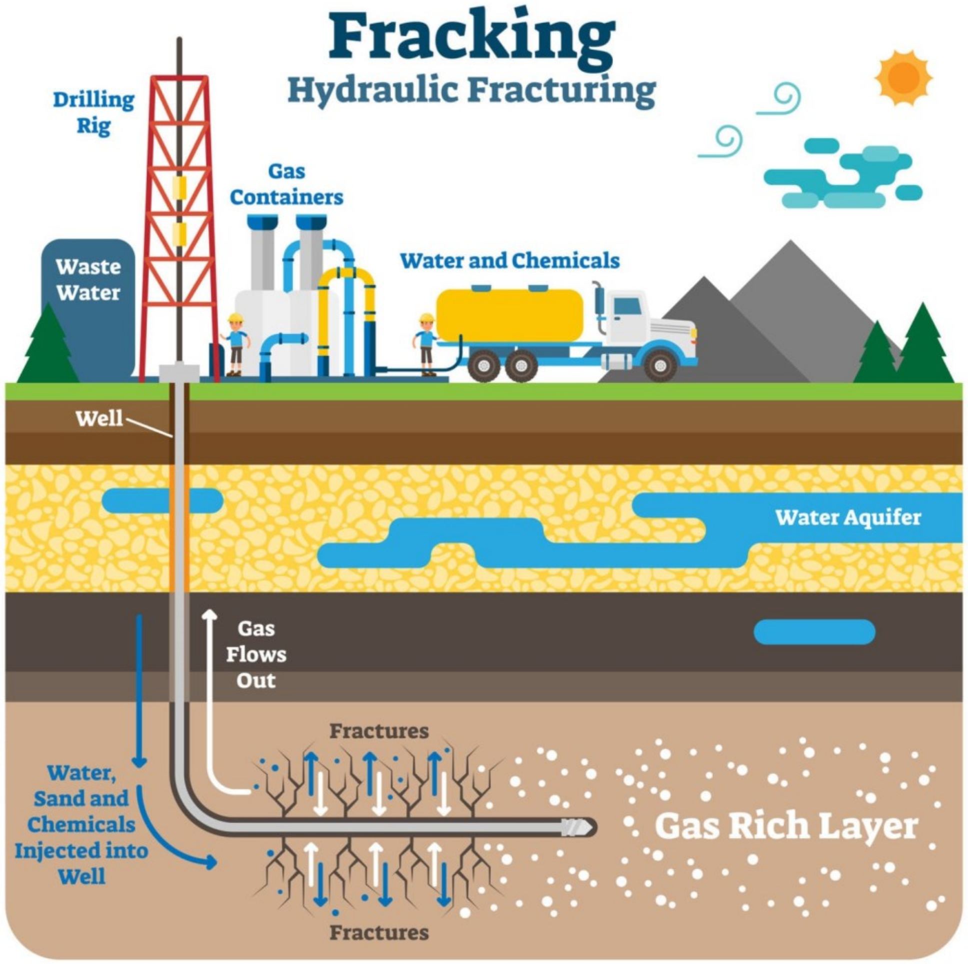
[1] Department of Mechanical and Aeronautical Engineering
Clarkson University, Potsdam, NY

[2] National Energy Technology Laboratory
US Department of Energy, Morgantown, WV

Outline

- **Introduction**
  - ❑Hydraulic fracturing
  - ❑CFD-DEM Code
  - ❑Rough-Wall Fractures
- **Results**
  - **I. CFDEM® solver**
    - ❑Fracture coverage
  - **II. Star CCM + solver**
    - ❑No roughness
    - ❑Fracture coverage
    - ❑Characteristics in time
    - ❑Particle displacement in time
- **Conclusions and future study**

Introduction - Hydraulic Fracturing



www.oilmanmagazine.com

Purpose

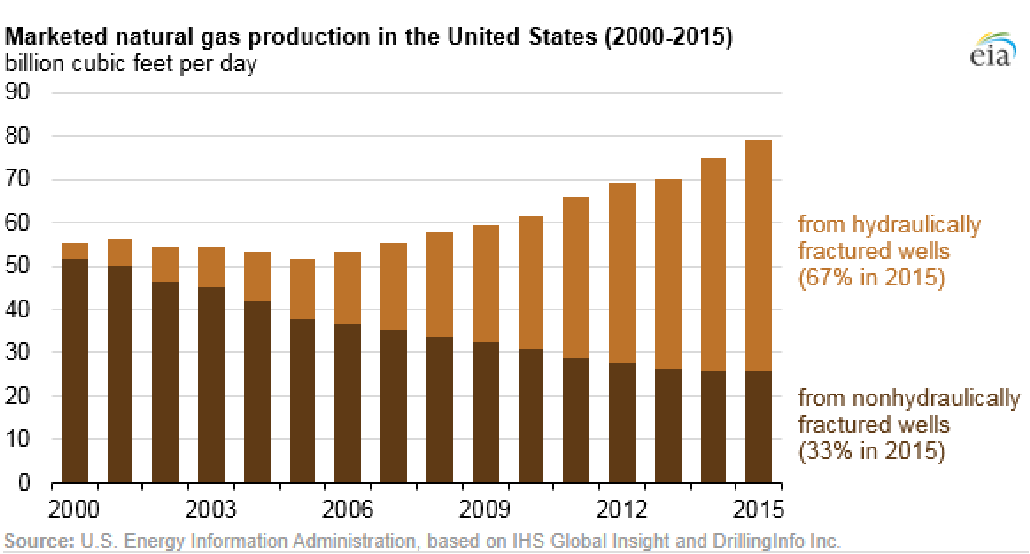
- Releases petroleum or natural gas trapped in shale rock formations.

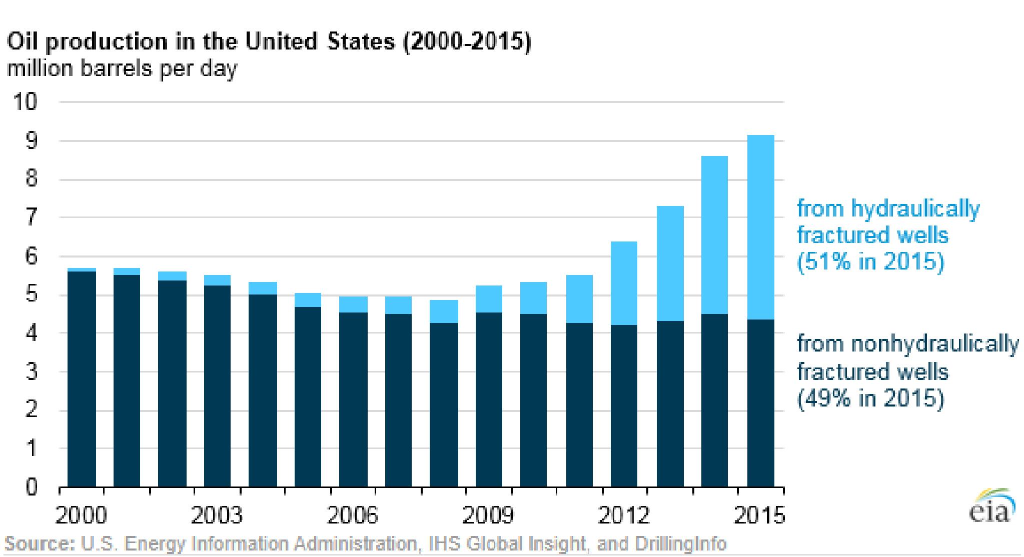
Fracturing Procedure

- Drilling a horizontal well in the targeted formation and inserting a steel pipe with holes into the wellbore.
- Pressurized liquid and proppants are injected into wellbores.
- The targeted formation fractures.
- Injection process is ceased, and the fracking liquids is drained.
- Proppant keep the rock fractures open and allows gas/oil production

NATIONAL ENERGY TECHNOLOGY LABORATORY

Introduction - Hydraulic Fracturing





Why it is important?

- Shale gas production increased from 4% in 2005 to 24% in 2012.
- 300K hydraulically fractured wells in 21 states in 2015.
- Fracking generated 67% of natural gas and 43% of crude oil in 2015.
- In 2013 at least 2 million oil/gas wells were fractured.

Motivation

- Experimental studies are expensive and hard to perform
- Numerical studies with a realistic geometry for the fracture are scarce
- The effect of proppant's properties on the fracture coverage is not clear

Objectives

- Develop a computational model for proppant flows in rock fractures
- Assess the facture coverage for different conditions

Solution Methods

- Computational models
  I. CFDEM® solver
  II. Star CCM + solver

Introduction - CFD-DEM Code

Experimental study is expensive and hard to perform

↓

Numerical methods

↓

Two-phase particle-laden flow

↓

CFDEM®coupling (Solver 1): OpenFOAM + LIGGGHTS	Star CCM + (Solver 2):
CFD-DEM (4-way coupling)	CFD-DEM (4-way coupling)
Numerically more expensive High fidelity numerical simulations	User friendly Easier visualizations Faster

NATIONAL ENERGY TECHNOLOGY LABORATORY

Introduction - Rough wall Fracture, CFD-DEM Code

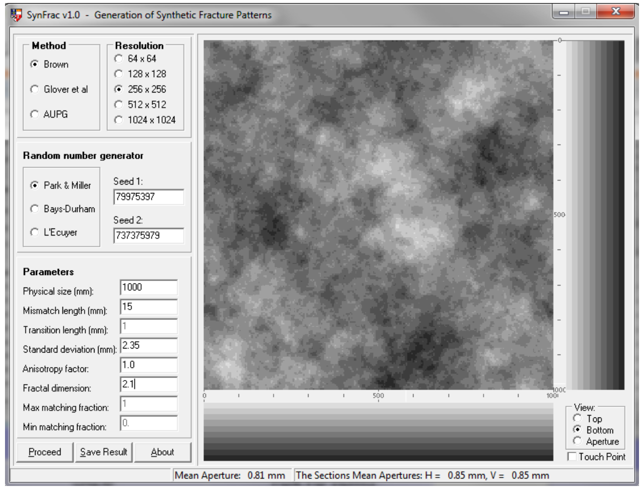
SynFrac.exe
GenerateGeometry

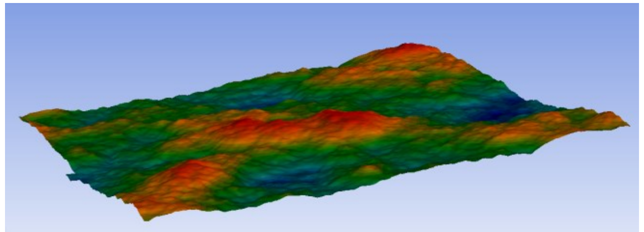
MATLAB R2018b
App

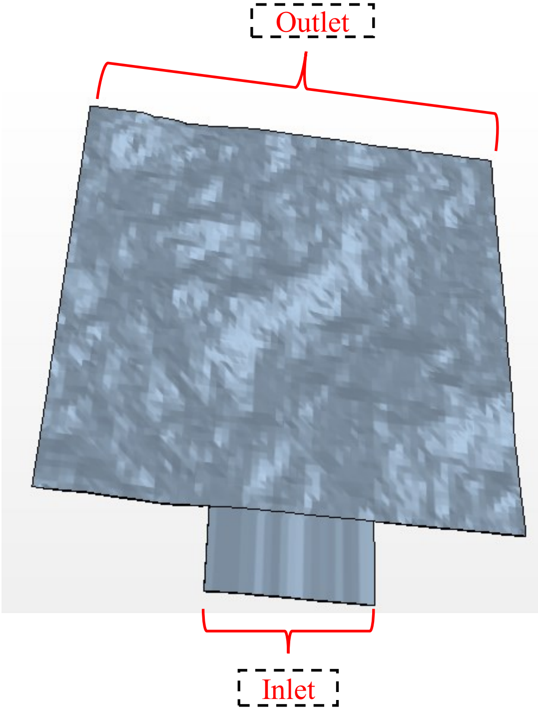
Simulation
CFD-DEM solver

CFDEM®project

Simcenter STAR-CCM+







.frt file

.srt file

- **Introduction**
  - Hydraulic fracturing
  - CFD-DEM Code
  - Rough-Walled Fractures
- **Results**

I. First solver (CFDEM®)
  - Fracture coverage

II. Second solver (Star CCM +)
  - No roughness
  - Fracture coverage
  - Characteristic in time
  - Particle's displacement

- **Conclusion and future study**

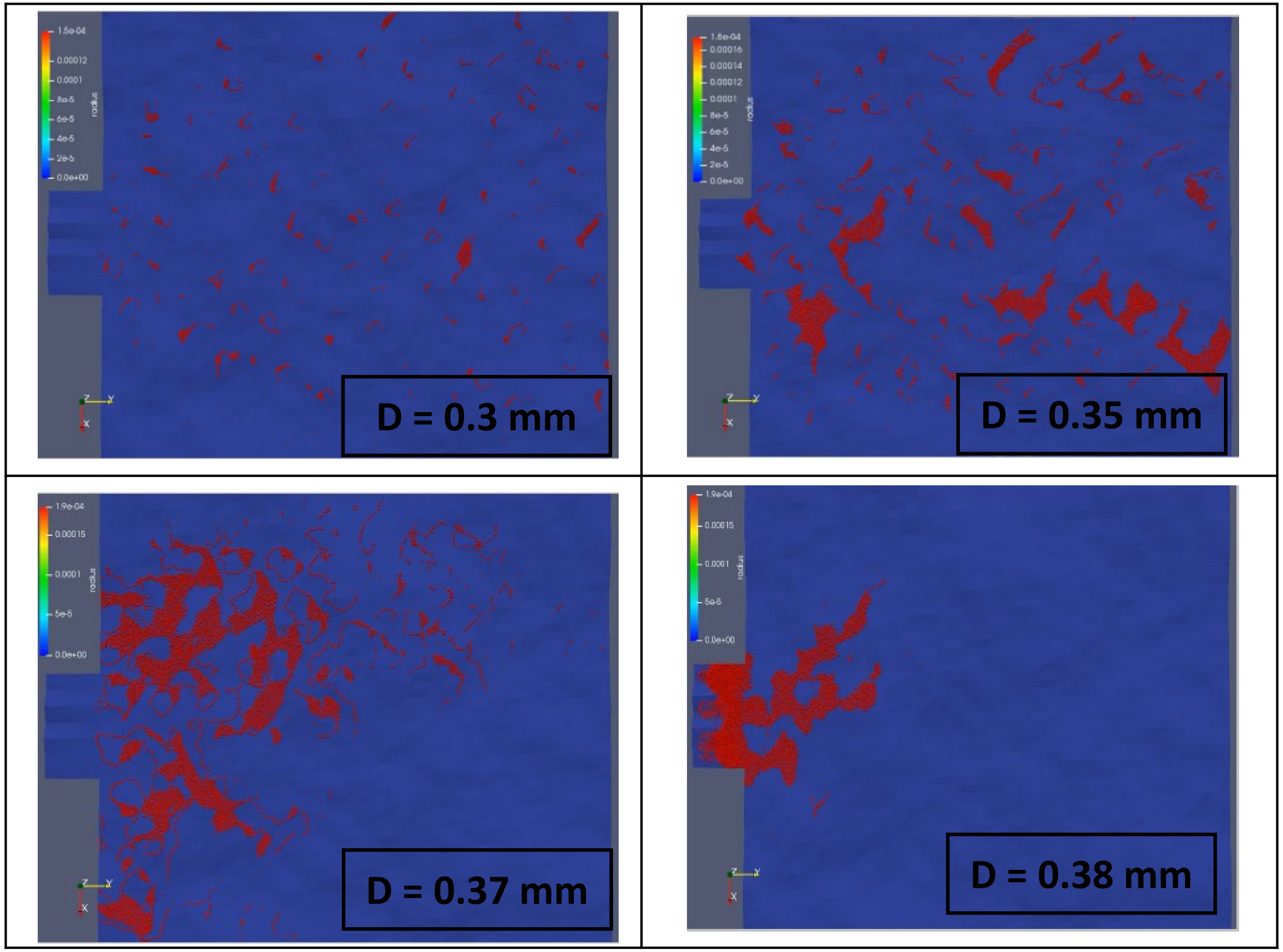
NATIONAL ENERGY TECHNOLOGY LABORATORY

Results – First Solver, CFDEM Code

- Mean Aperture size = 0.4 mm
- Fracture Dimension = 0.1 × 0.1 m
- Slick water + Sand
- 1000 Particle per second
- Inlet pressure = 10 m^2/s^2 normalized by the fluid density

Slick water:
μ = 0.001006 Pa-s
ρ = 1006.561 kg/ m^3

Fracture coverage



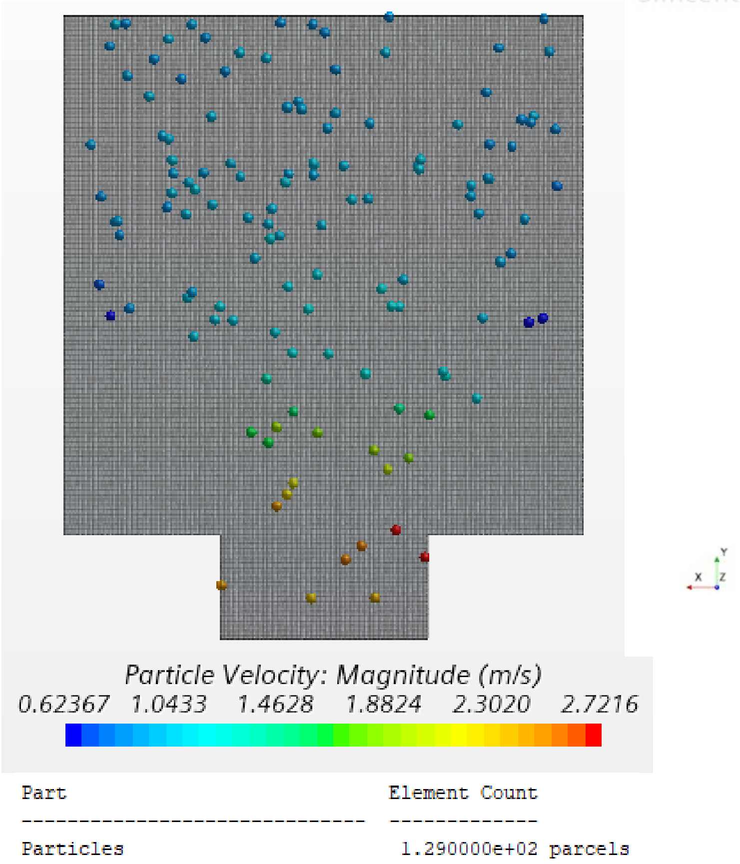
NATIONAL ENERGY TECHNOLOGY LABORATORY

Results – Second Solver, Star CCM + Code

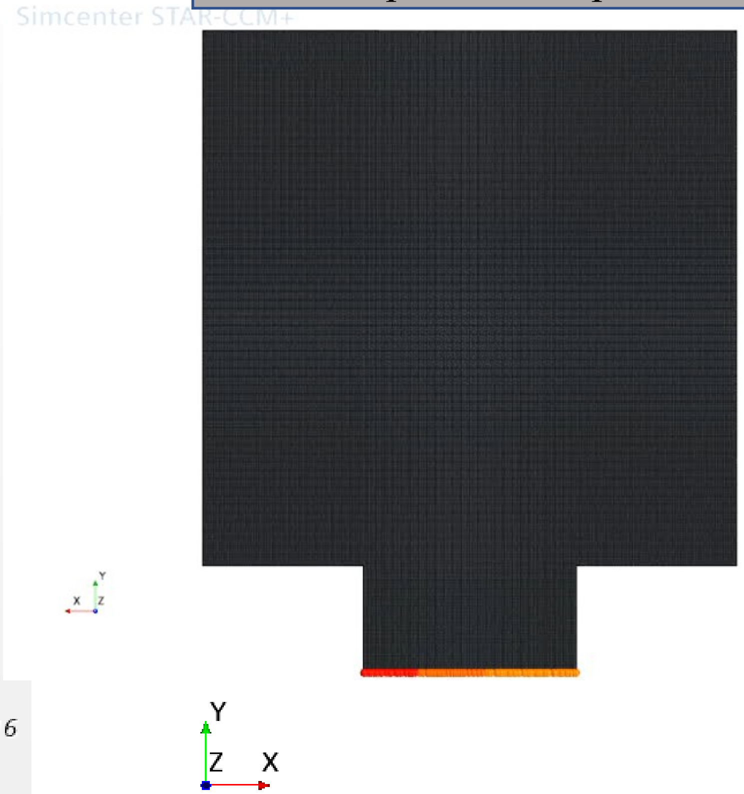
Smooth fracture

- Smooth walls
- Fracture Dimension = 100 × 100 × 0.4 mm
- Slick water + sand
- Gravity in –Z direction
- 1000 Particle per second
- Inlet pressure = 10 m^2/s^2 normalized by the fluid density

Particle's distribution after 5s



Movie of particles displacement



- **Introduction**
  - ❑ Hydraulic fracturing
  - ❑ CFD-DEM Code
  - ❑ Rough-Walled Fractures
- **Results**

I. First solver (CFDEM®)
- ❑ Fracture coverage

II. Second solver (Star CCM +)
- ❑ No roughness
- ❑ Fracture coverage
- ❑ Characteristic in time
- ❑ Particle's displacement

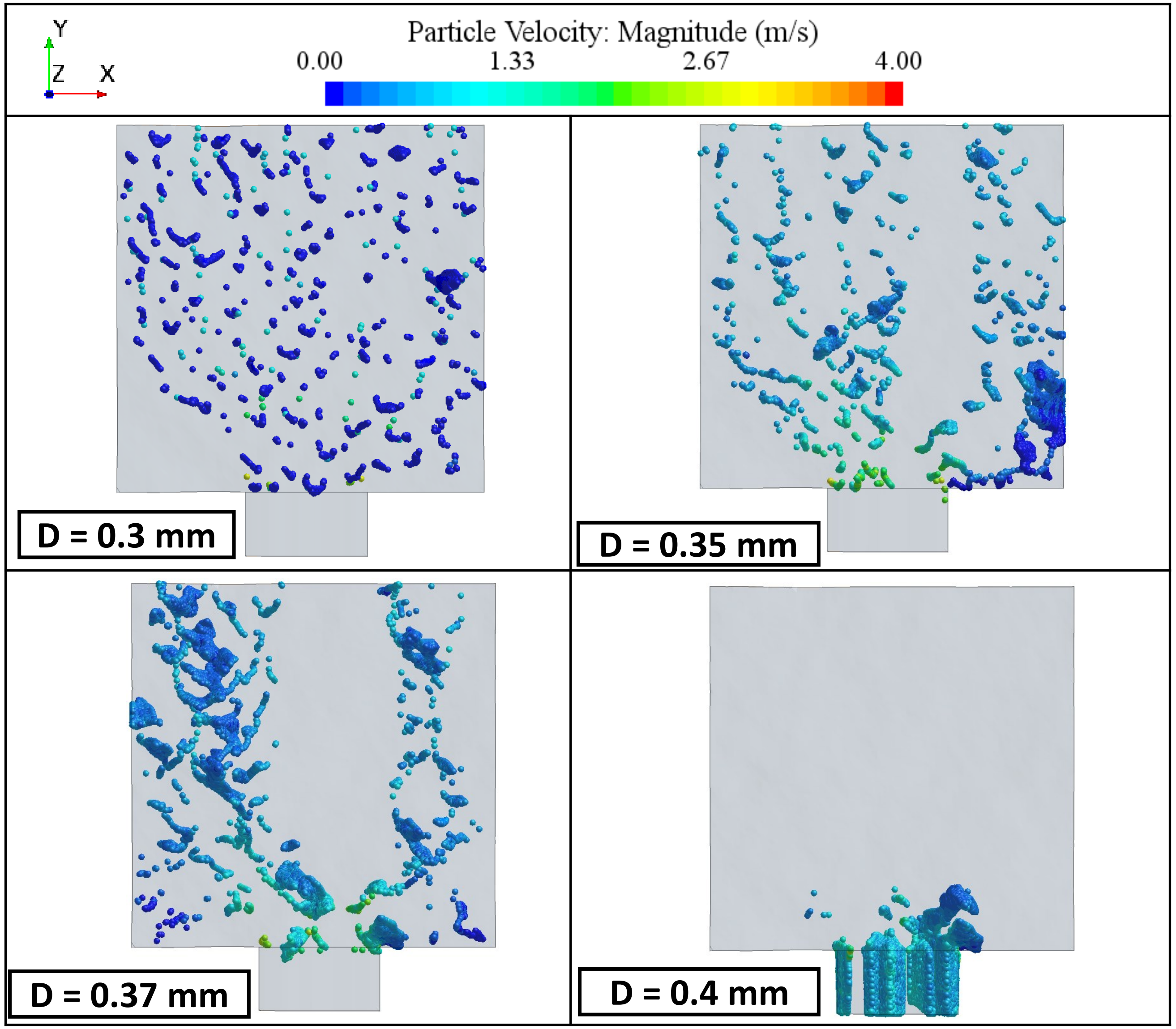
- **Conclusion and future study**

NATIONAL ENERGY TECHNOLOGY LABORATORY

Results – Second Solver, Star CCM + Code

Fracture coverage

- Mean Aperture size = 0.4 mm
- Gravity in –Z direction
- Fracture Dimension = 0.1 × 0.1 m
- Slick water + sand
- 1000 Particle per second
- Inlet pressure = 10 m^2 / s^2 normalized by the fluid density

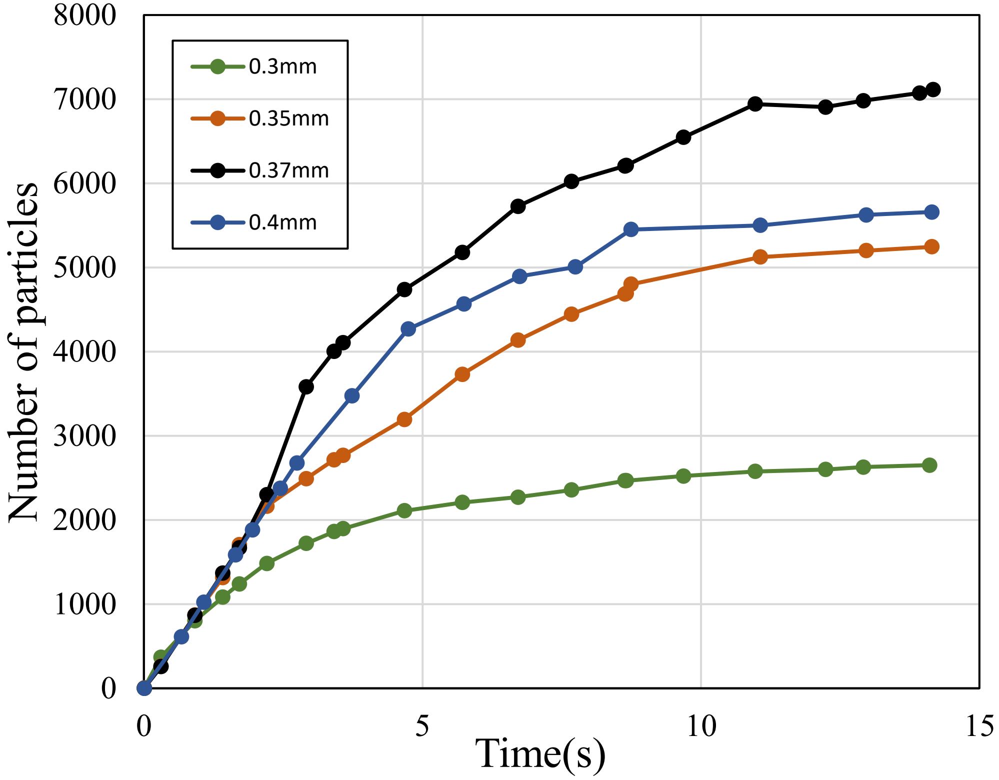


- **Introduction**
  - Hydraulic fracturing
  - CFD-DEM Code
  - Rough-Walled Fractures
- **Results**
- **I. First solver (CFDEM®)**
  - Fracture coverage
- **II. Second solver (Star CCM +)**
  - No roughness
  - Fracture coverage
  - Characteristic in time
  - Particle's displacement
- **Conclusion and future study**

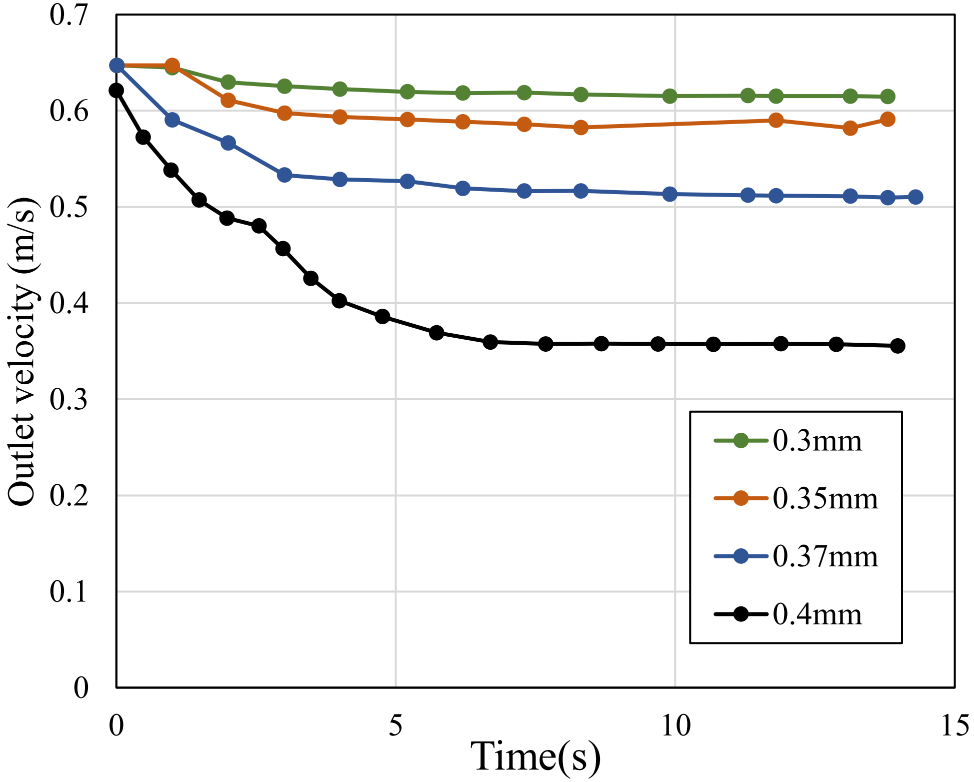
NATIONAL ENERGY TECHNOLOGY LABORATORY

Results – Second Solver, Star CCM + Code

Number of particles in the fracture over time



Fluid flow velocity at the outlet of the fracture



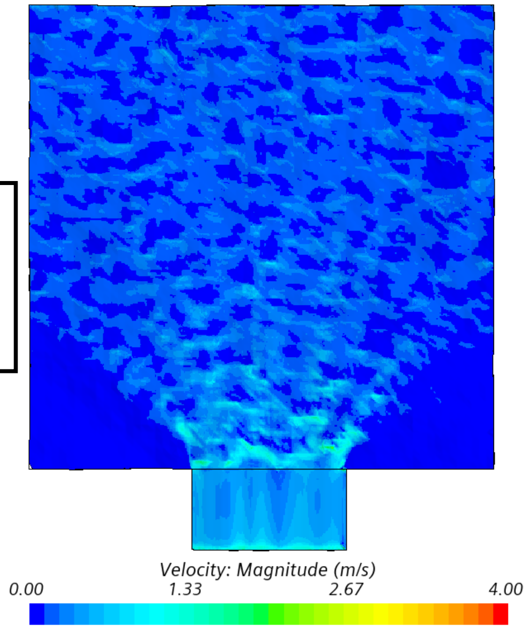
- Mean Aperture size = 0.4 mm
- Gravity in –Z direction
- Fracture Dimension = 0.1 × 0.1 m
- Slick water + Sand
- 1000 Particle per second
- Inlet pressure = 10 m^2/s^2 normalized by the fluid density

NATIONAL ENERGY TECHNOLOGY LABORATORY

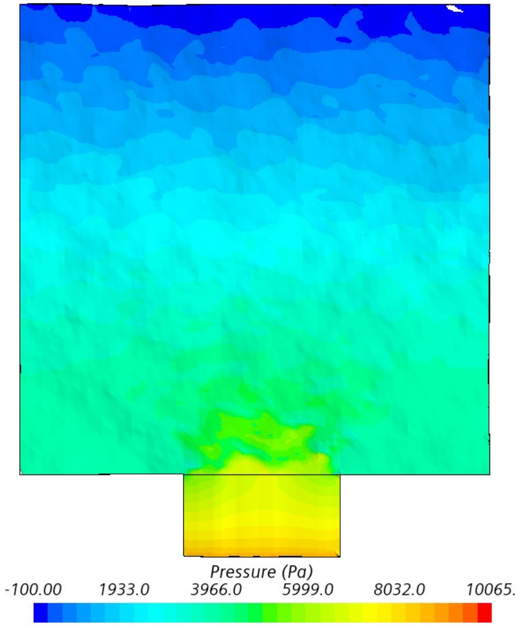
Results – Second Solver, Star CCM + Code

- Mean Aperture size = 0.4 mm
- Gravity in –Z direction
- Fracture Dimension = 0.1 × 0.1 m
- Slick water + sand
- 1000 Particle per second
- Inlet pressure = 10 m^2 / s^2 normalized by the fluid density

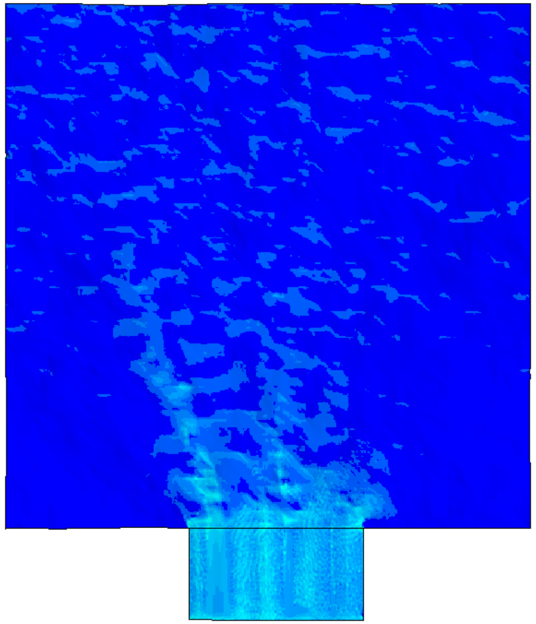
Contour of Velocity D = 0.3 mm



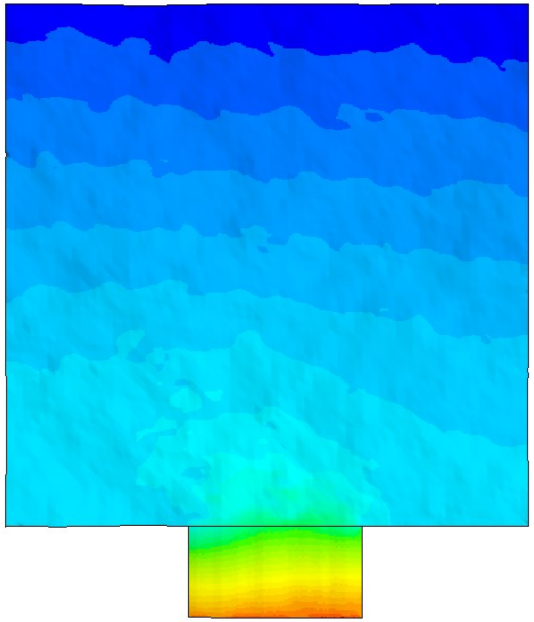
Contour of Pressure D = 0.3 mm



Contour of Velocity D = 0.4 mm



Contour of Pressure D = 0.4 mm



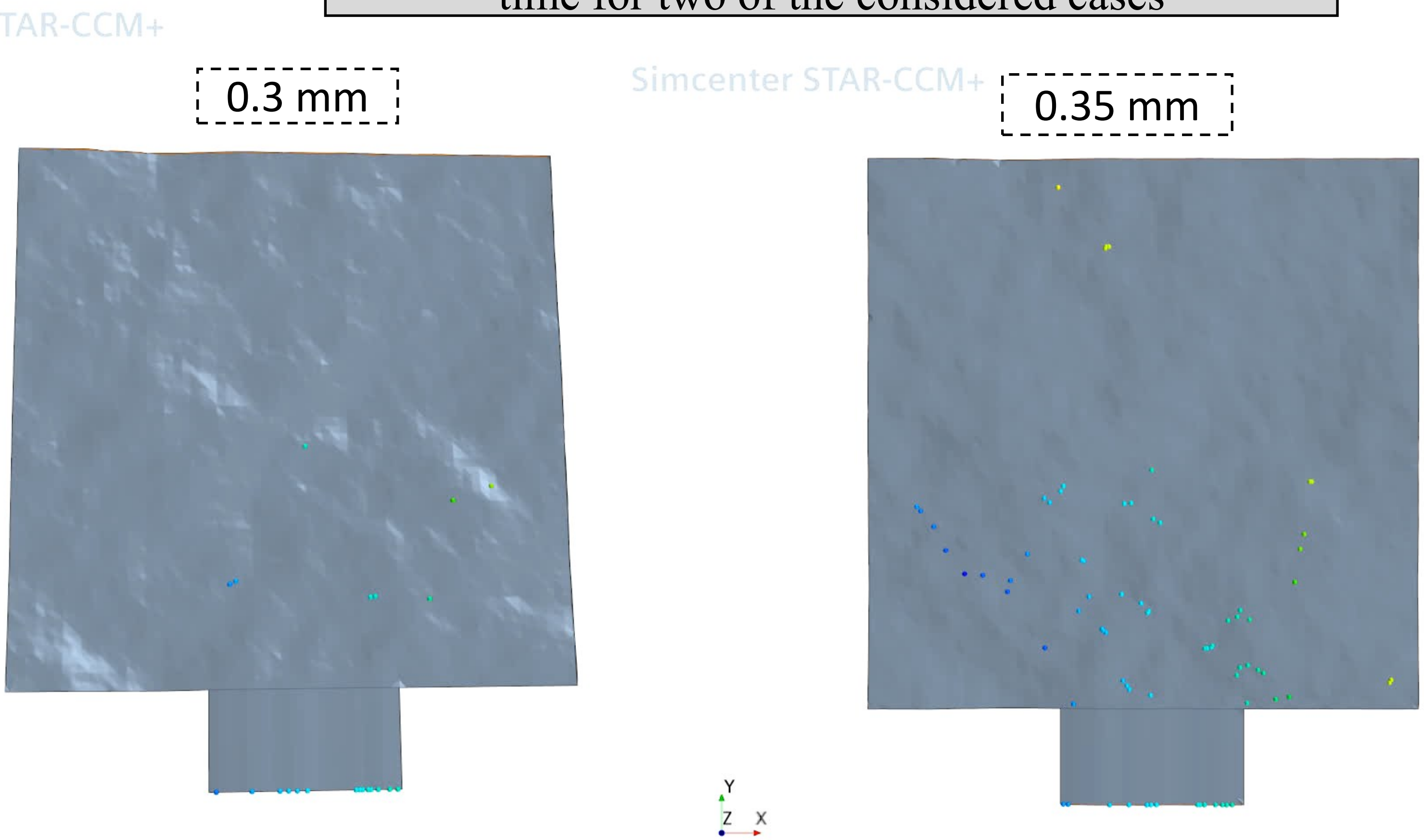
Results – Second Solver, Star CCM + Code

Particle motion

Movie of particles injection and displacement over time for two of the considered cases

0.3 mm

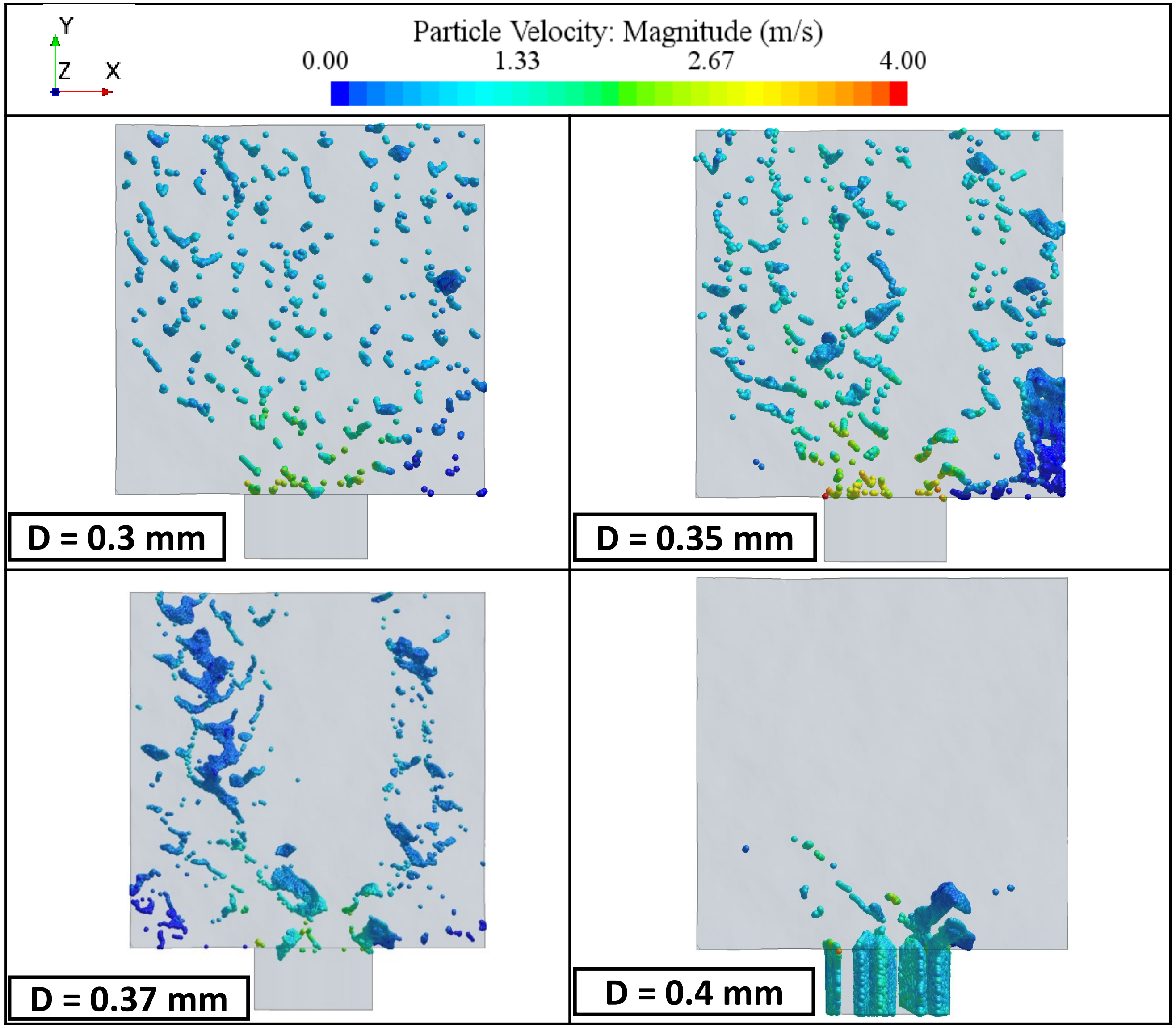
0.35 mm



Results – Second Solver, Star CCM + Code

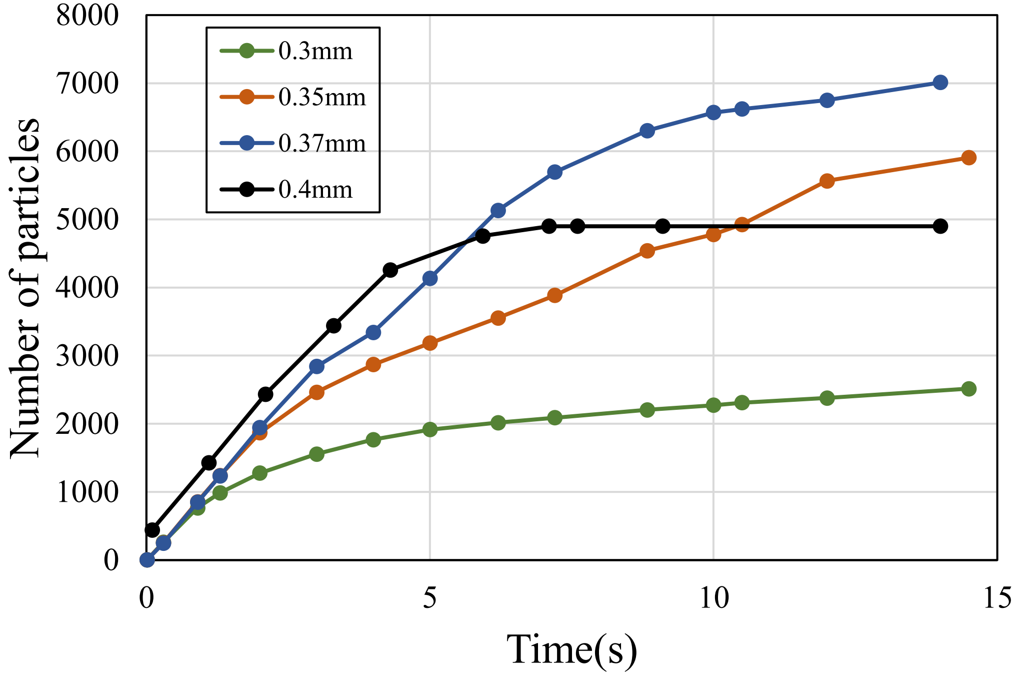
Fracture coverage

- Gravity in –Y direction
- Mean Aperture size = 0.4 mm
- Fracture Dimension = 0.1 × 0.1 m
- Slick water + sand
- 1000 Particle per second
- Inlet pressure = 10 m^2 / s^2 normalized by the fluid density



Results – Second Solver, Star CCM + Code

Number of particles in the fracture over time



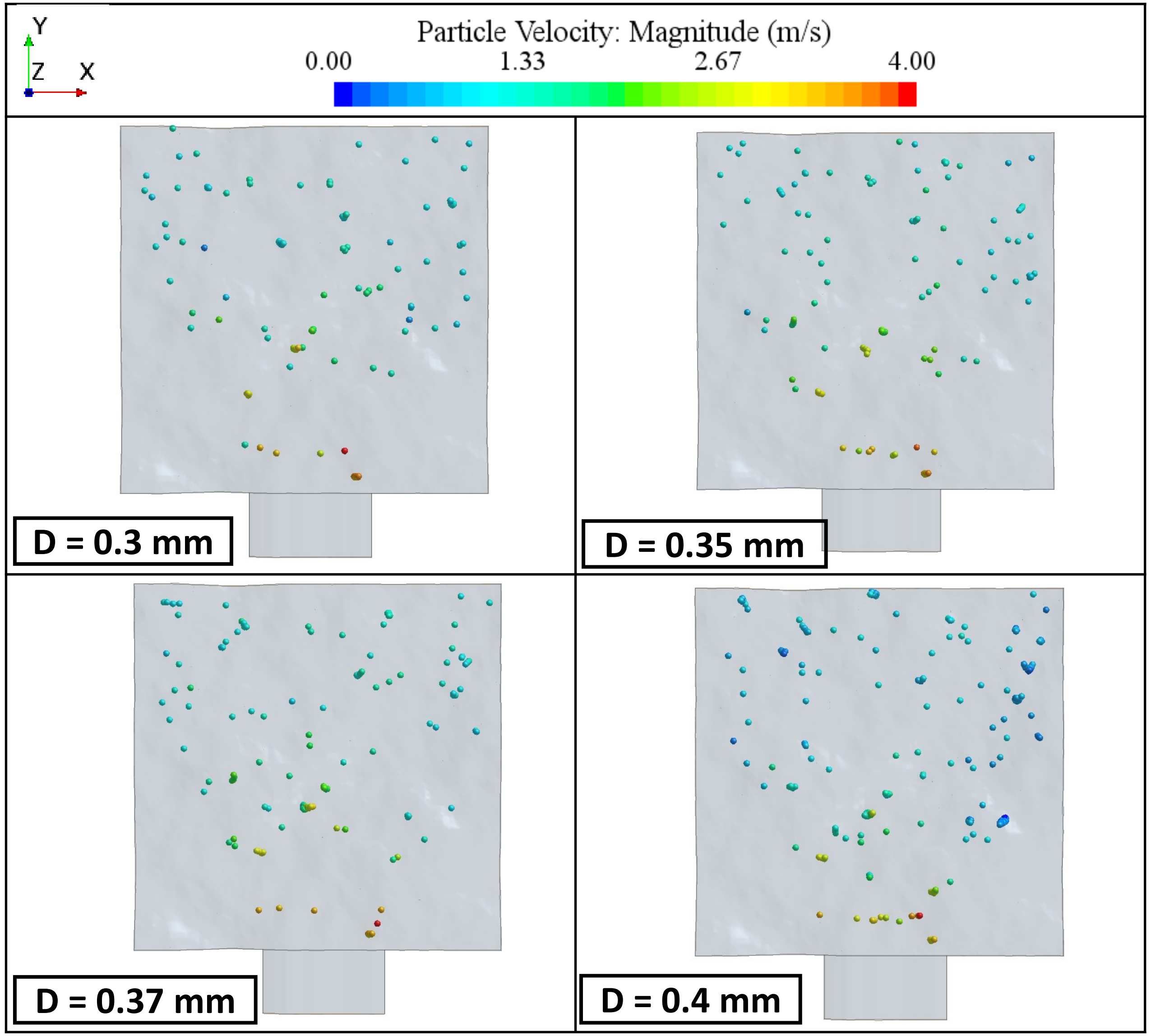
- Gravity in –Y direction
- Mean Aperture size = 0.4 mm
- Fracture Dimension = 0.1 × 0.1 m
- Slick water + Sand
- 1000 Particle per second
- Inlet pressure = 10 $m^2/\ s^2$ normalized by the fluid density

NATIONAL ENERGY TECHNOLOGY LABORATORY

Results – Second Solver, Star CCM + Code

Fracture coverage

- Mean Aperture size = 0.8 mm
- Gravity in –Z direction
- Fracture Dimension = 0.1 × 0.1 m
- Slick water + sand
- 1000 Particle per second
- Inlet pressure = 10 m^2 / s^2 normalized by the fluid density

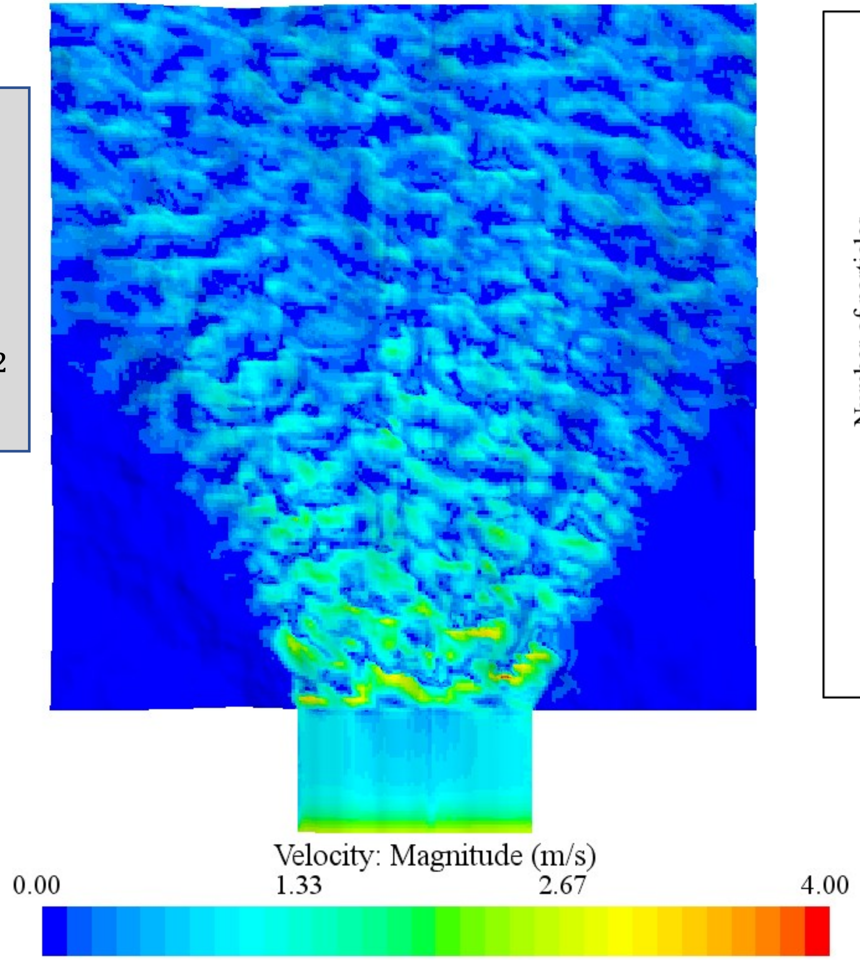


NATIONAL ENERGY TECHNOLOGY LABORATORY

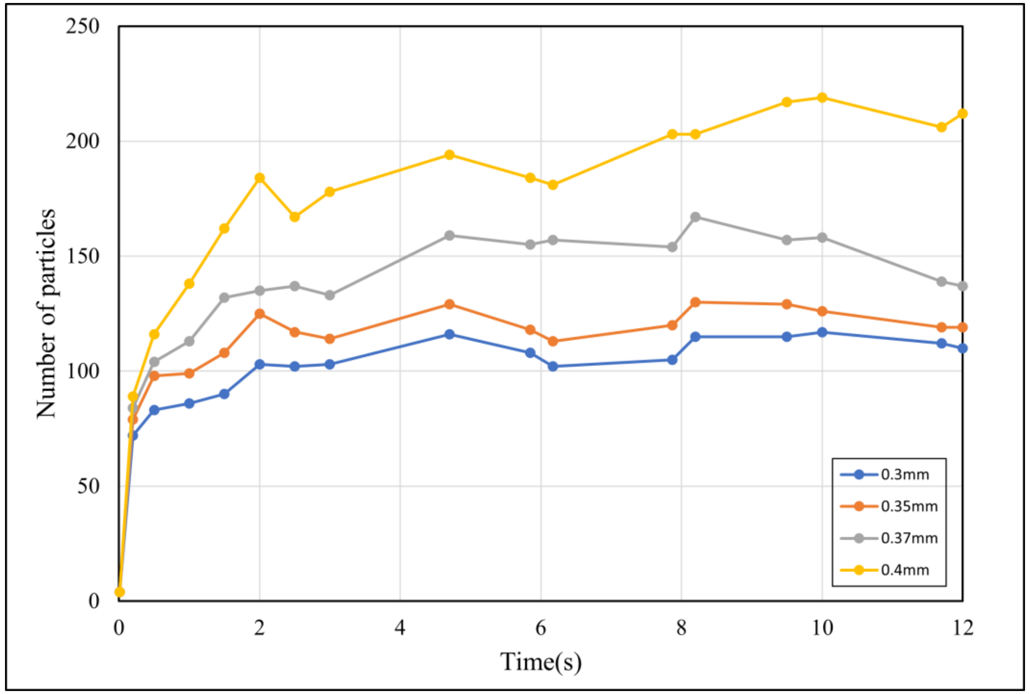
Results – Second Solver, Star CCM + Code

- Mean Aperture size = 0.8 mm
- Gravity in –Z direction
- Fracture Dimension = 0.1 × 0.1 m
- Slick water + sand
- 1000 Particle per second
- Inlet pressure = 10 m^2 / s^2 normalized by the fluid density

Contour of Velocity D = 0.3 mm



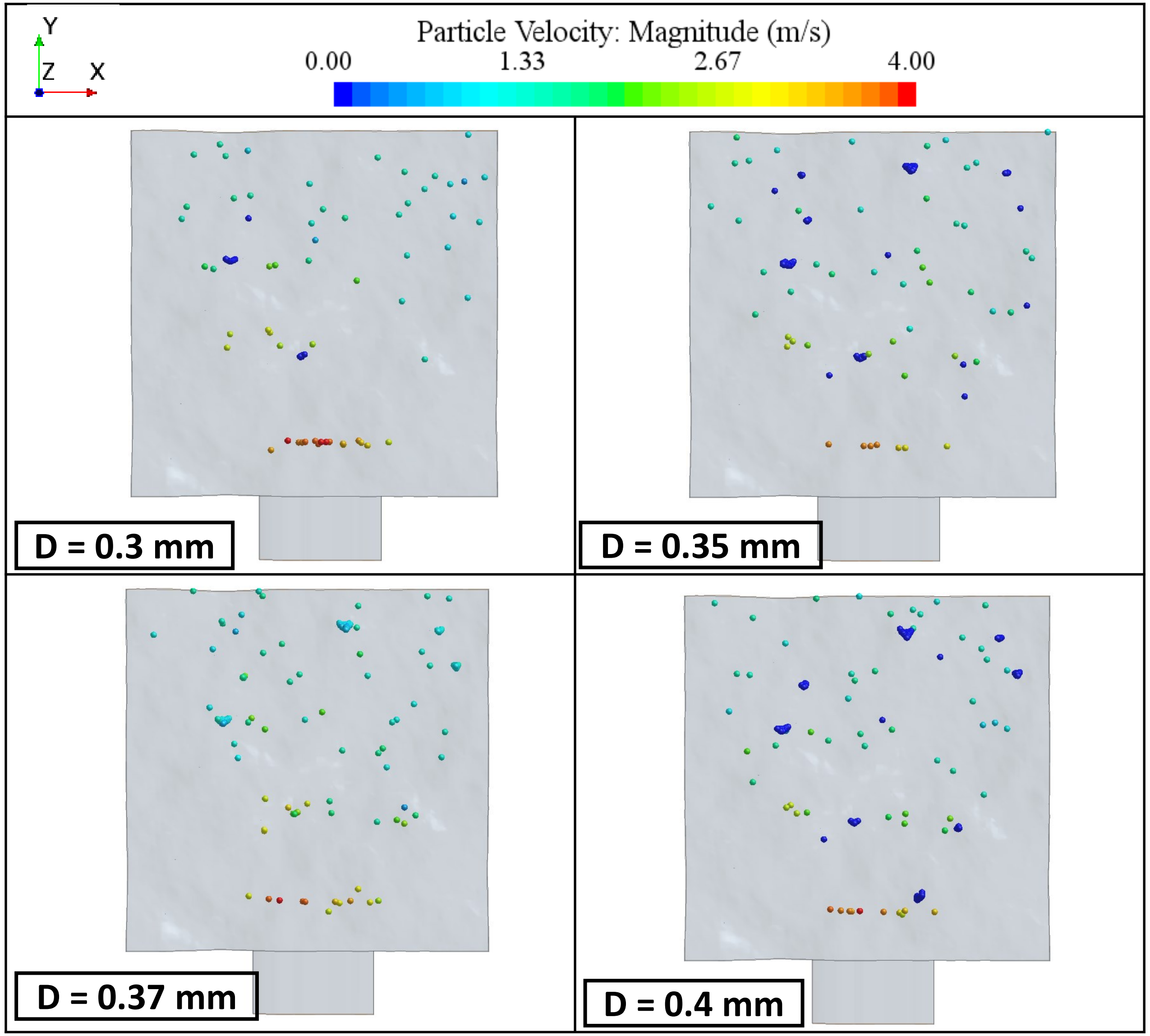
Number of particles in the fracture over time



Results – Second Solver, Star CCM + Code

Fracture coverage

- Mean Aperture size = 1 mm
- Gravity in –Z direction
- Fracture Dimension = 0.1 × 0.1 m
- Slick water + sand
- 1000 Particle per second
- Inlet pressure = 10 m^2 / s^2 normalized by the fluid density

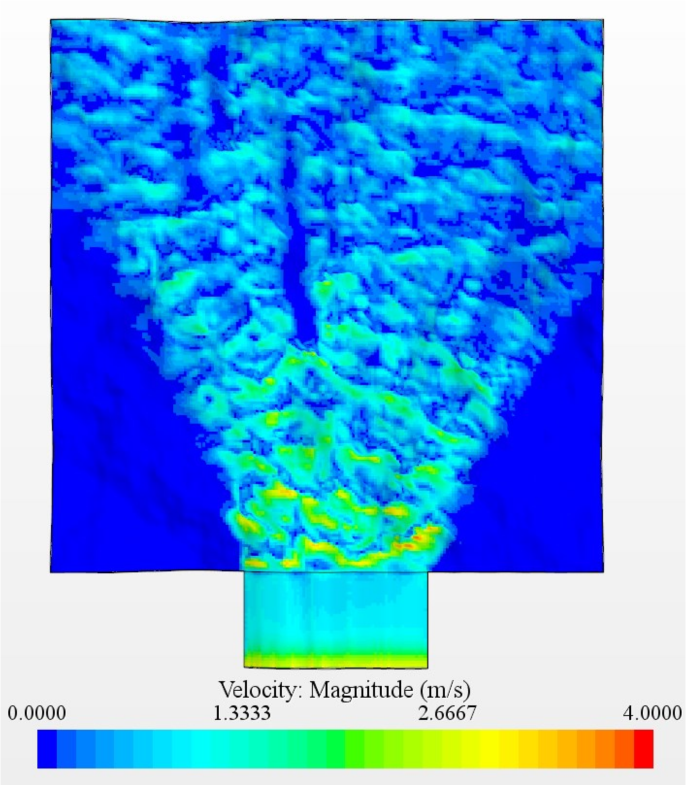


NATIONAL ENERGY TECHNOLOGY LABORATORY

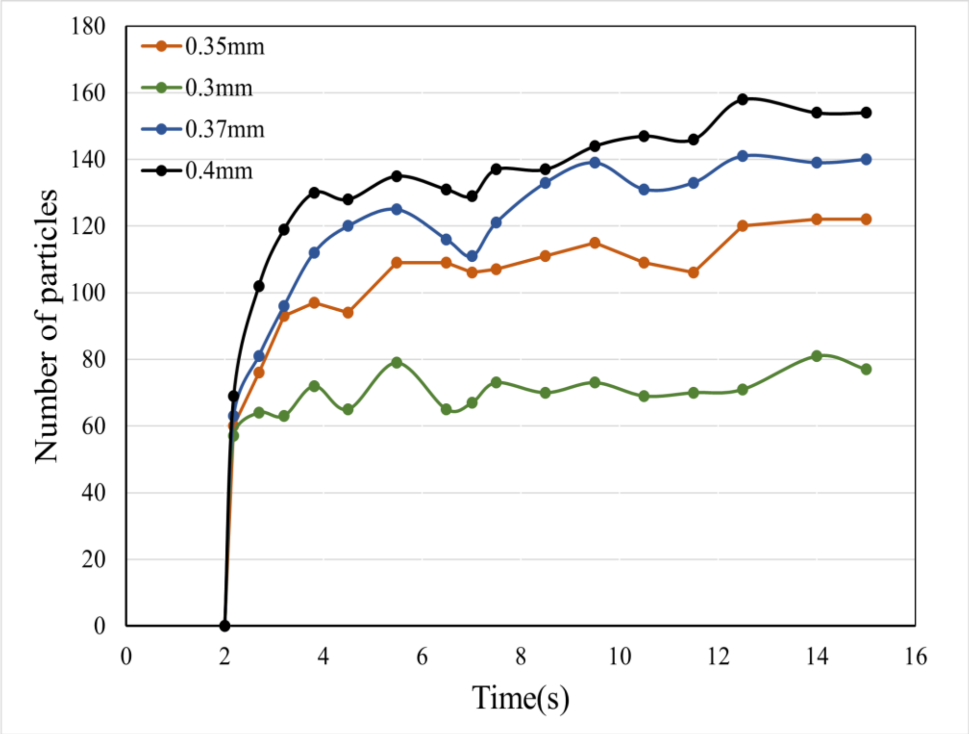
Results – Second Solver, Star CCM + Code

- Mean Aperture size = 1 mm
- Gravity in –Z direction
- Fracture Dimension = 0.1 × 0.1 m
- Slick water + sand
- 1000 Particle per second
- Inlet pressure = 10 m^2 / s^2 normalized by the fluid density

Contour of Velocity D = 0.3 mm



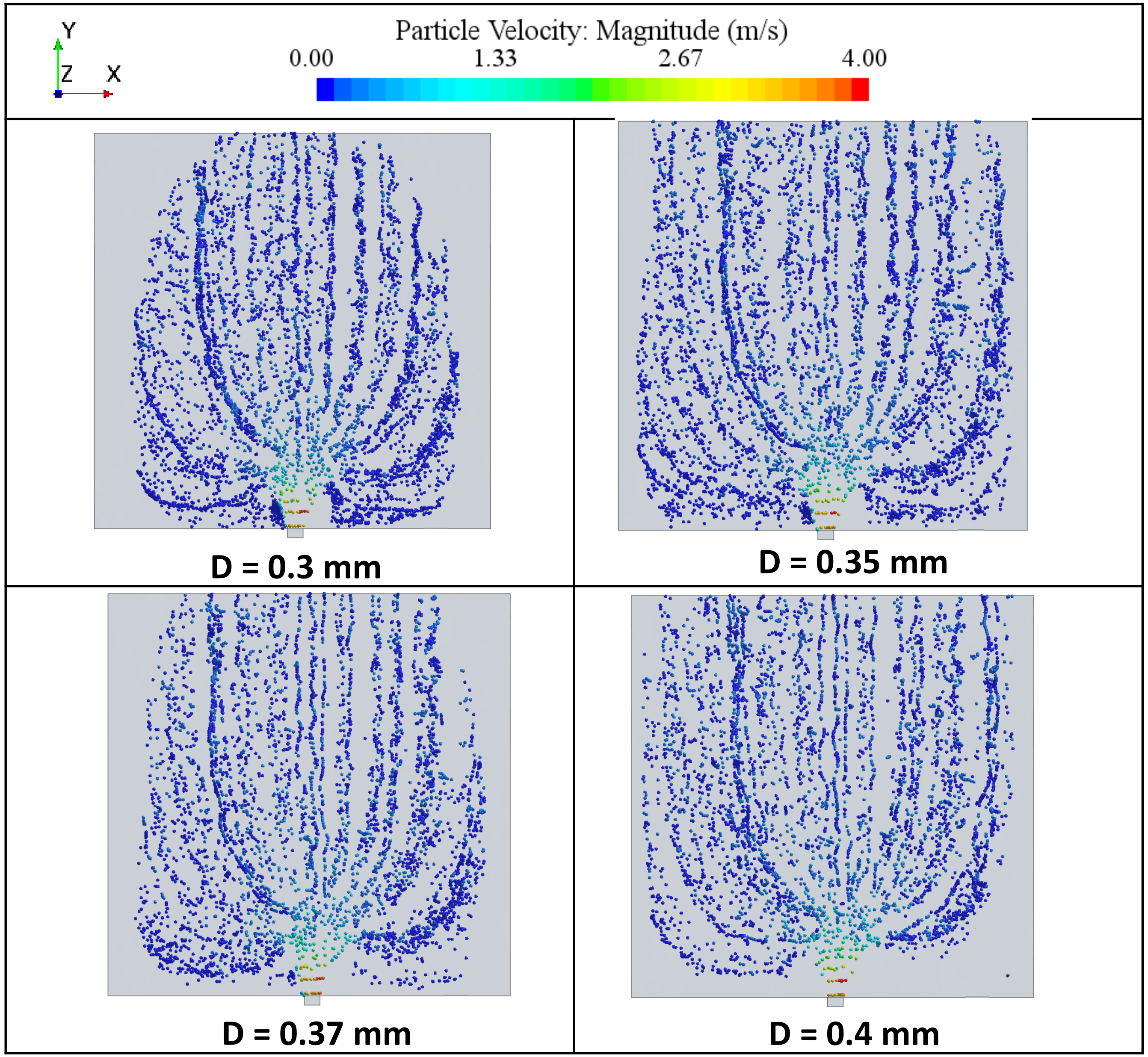
Number of particles in the fracture over time



Results – Second Solver, Star CCM + Code

Fracture coverage

- Mean Aperture size = 0.8 mm
- Gravity in –Z direction
- Fracture Dimension = 1 × 1 m
- Slick water + sand
- 1000 Particle per second
- Inlet pressure = 10 m^2 / s^2 normalized by the fluid density



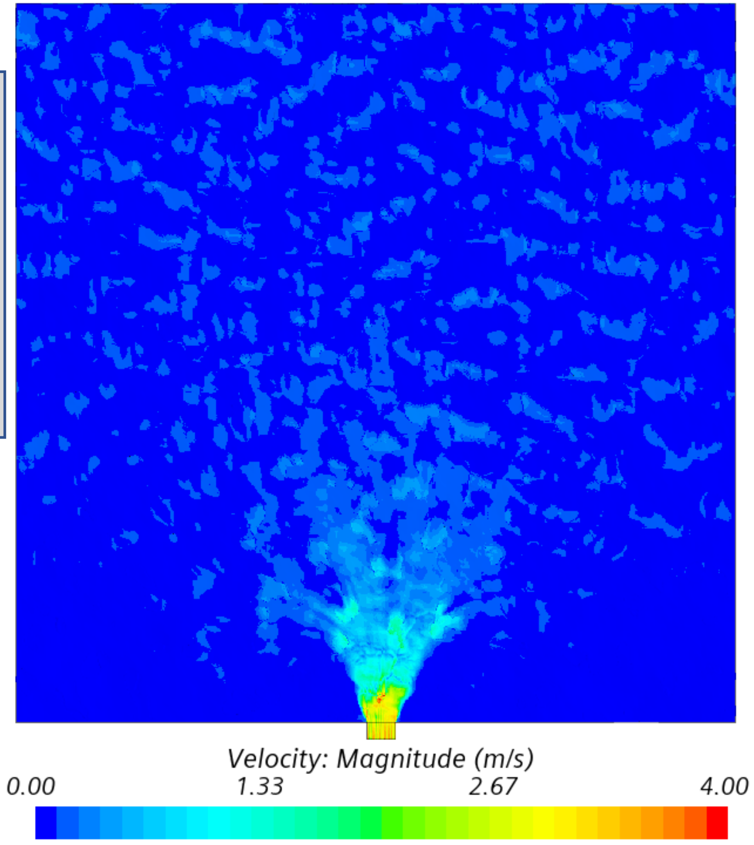
NATIONAL ENERGY TECHNOLOGY LABORATORY

Results – Second Solver, Star CCM + Code

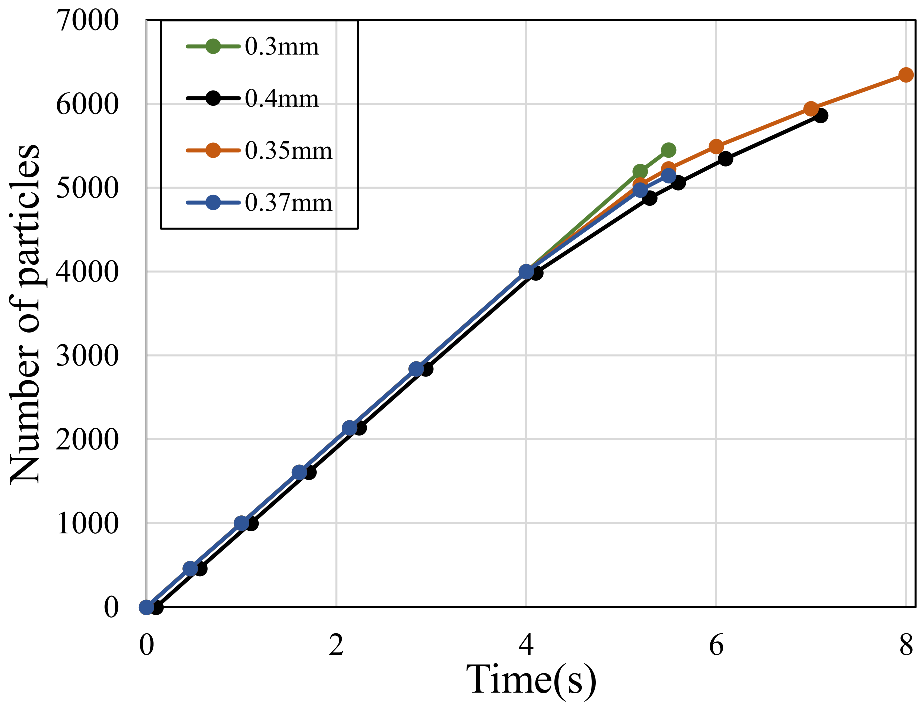
Fluid velocity

- Mean Aperture size =0.8 mm
- Gravity in –Z direction
- Fracture Dimension = 1 × 1 m
- Slick water + sand
- 1000 Particle per second
- Inlet pressure = 10 m^2 / s^2 normalized by the fluid density

Contour of Velocity D = 0.3 mm



Number of particles in the fracture over time

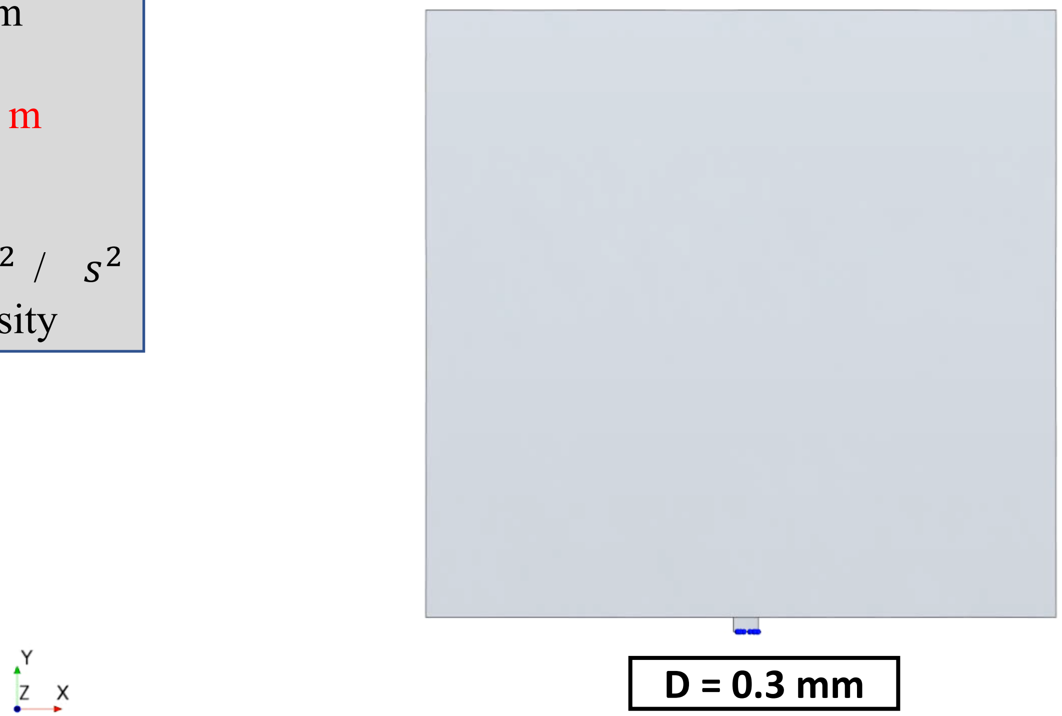


Results – Second Solver, Star CCM + Code

Particle motion

Movie of particles injection and displacement over time

- Mean Aperture size =0.8 mm
- Gravity in –Z direction
- Fracture Dimension = 1 × 1 m
- Slick water + sand
- 1000 Particle per second
- Inlet pressure = 10 m^2 / s^2 normalized by the fluid density



D = 0.3 mm

Conclusions

- A novel procedure to numerically study the proppant transport in fractures with realistic surface roughness was introduced.
- Sample results on effect of particle diameter on proppant distribution and coverage of the fracture were presented.
- The predictions of the solver are comparable:

Solver 1 (case 1): (Mean Aperture size = 0.4 mm)	**Solver 2 (case 1): (Mean Aperture size = 0.4 mm)**
D= 0.3 mm : 2.5% coverage after 10 s D= 0.35 mm : 9.3% coverage after 20 s	D= 0.3 mm : 2.1% D= 0.35 mm : 6.1% D= 0.37 mm : 8.2%

- There was an optimal proppant diameter for a given mean aperture for the maximum coverage. For an aperture height of 0.4 mm the mean diameter was 0.37 mm (92.5%).

NATIONAL ENERGY TECHNOLOGY LABORATORY

Conclusions

- For the mean aperture height much higher than particles diameters the effect of roughness is negligible

Future Study

- For the future study, the effect of fracture's characteristics including the mean fracture aperture and proppants properties on coverage would be investigated.
- The effect of gravity direction on the proppants transport and converge will be studied.

Thanks for your attention!

Questions?