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Computational Modeling of Proppant Transport in Fractures

G. Ahmadi,[1,2] A. A. Mofakham,[1] D.M. Crandall,[2] G.S. Bromhal[2]

[1] Clarkson University, Potsdam, NY 13699-5725

[2] National Energy Laboratory, US-DOE, Morgantown, WV 26505

ahmadi@clarkson.edu

Outline

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- **Flow through Rock Fractures**
  - CT Scanning of Rock Fractures
  - Single Phase Flows through Fractures
- **Proppant Transport**
  - Particle Trajectory Analysis
  - Deposition Pattern
- **Conclusions**

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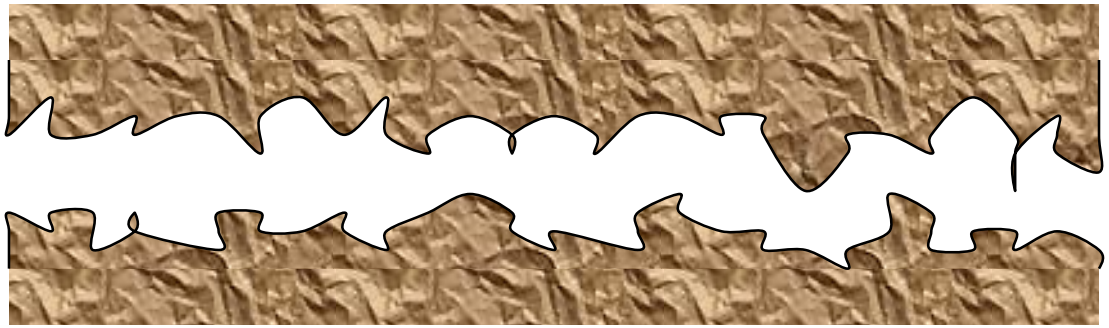
Flows through Rock Fractures



Fractures–Topology–Individual images with a high-magnification detail.

Sample diameter is 25 mm. Inset size is 5x5 mm.

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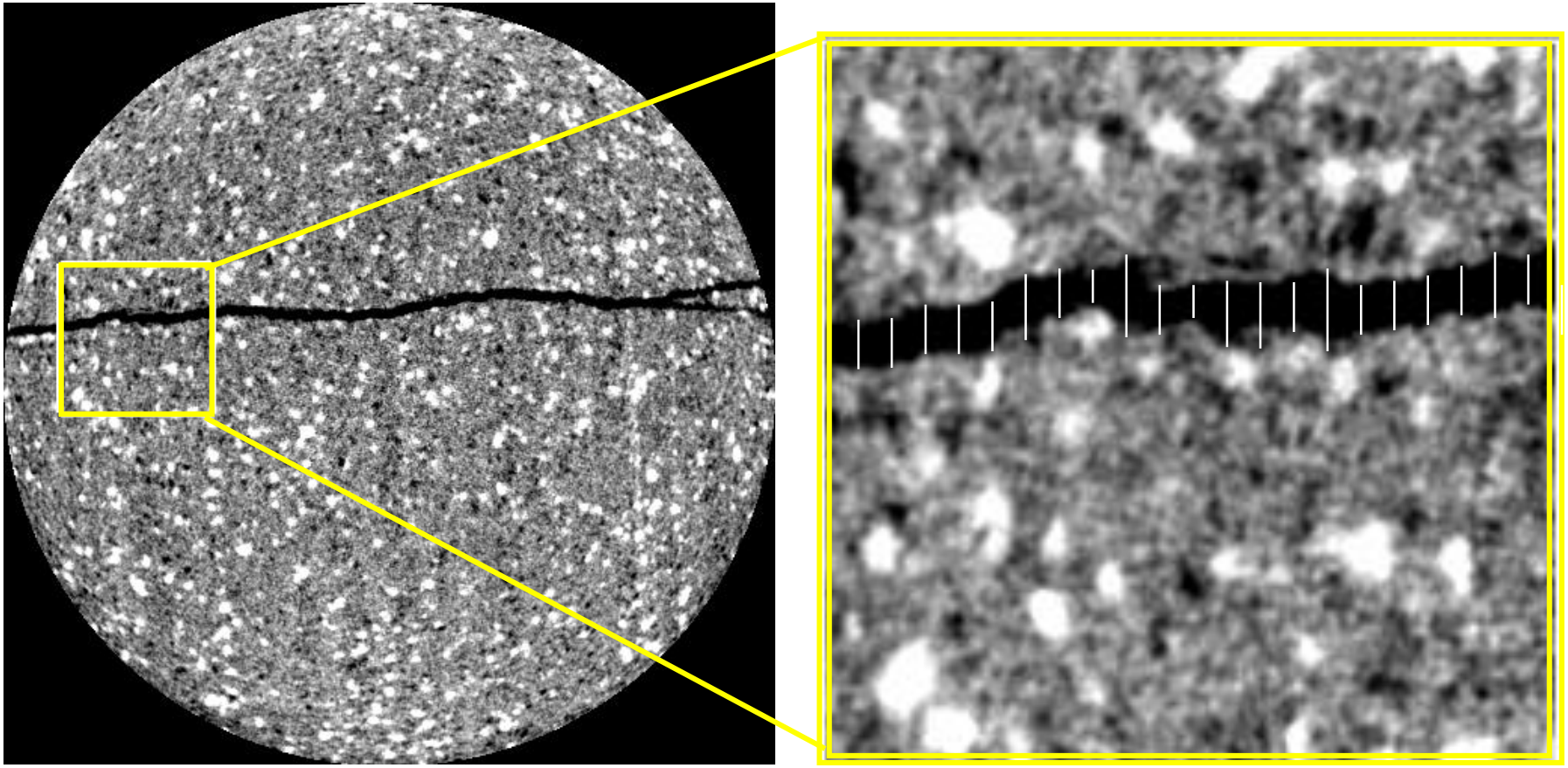

Fractures – Topology – Extracting Digital Fracture

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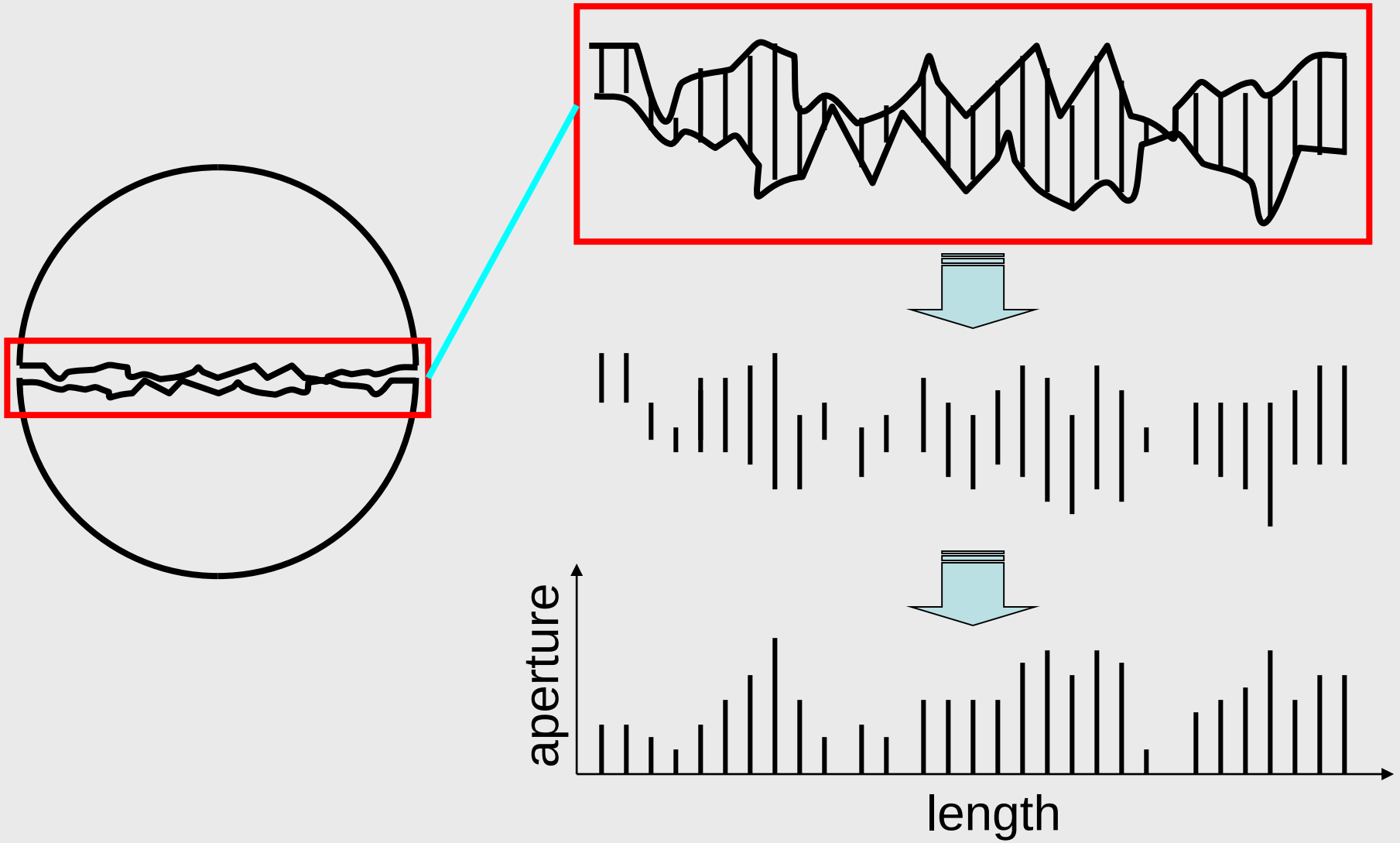

Fracture Cell

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Fracture/Sections

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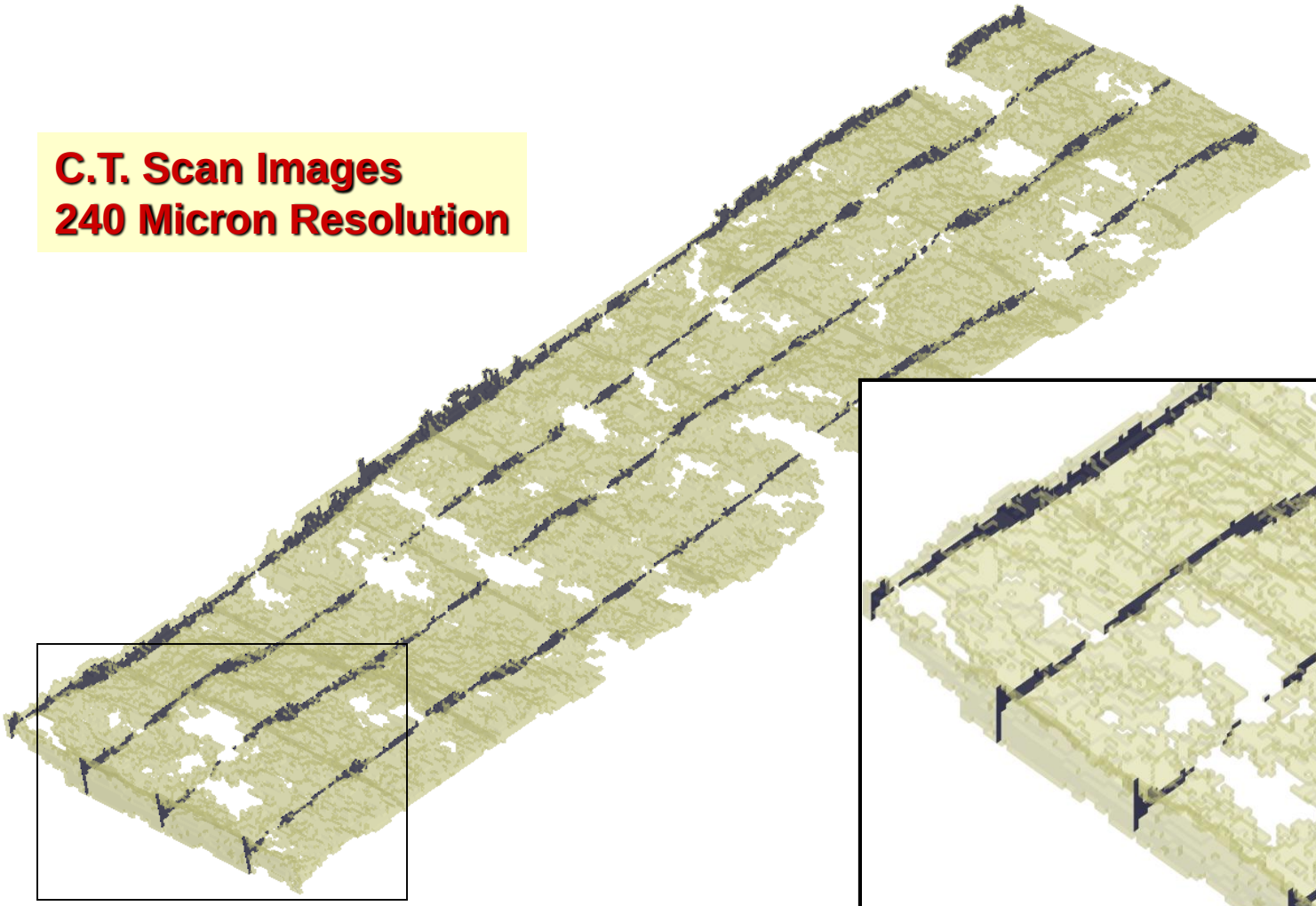
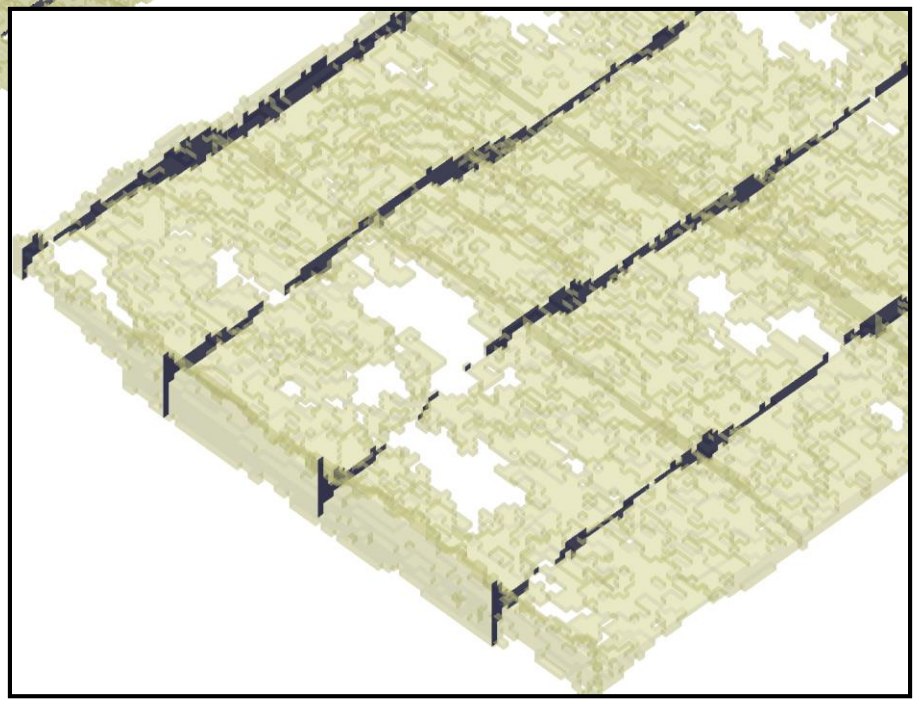
C.T. Scan Images
240 Micron Resolution





Fracture Sections

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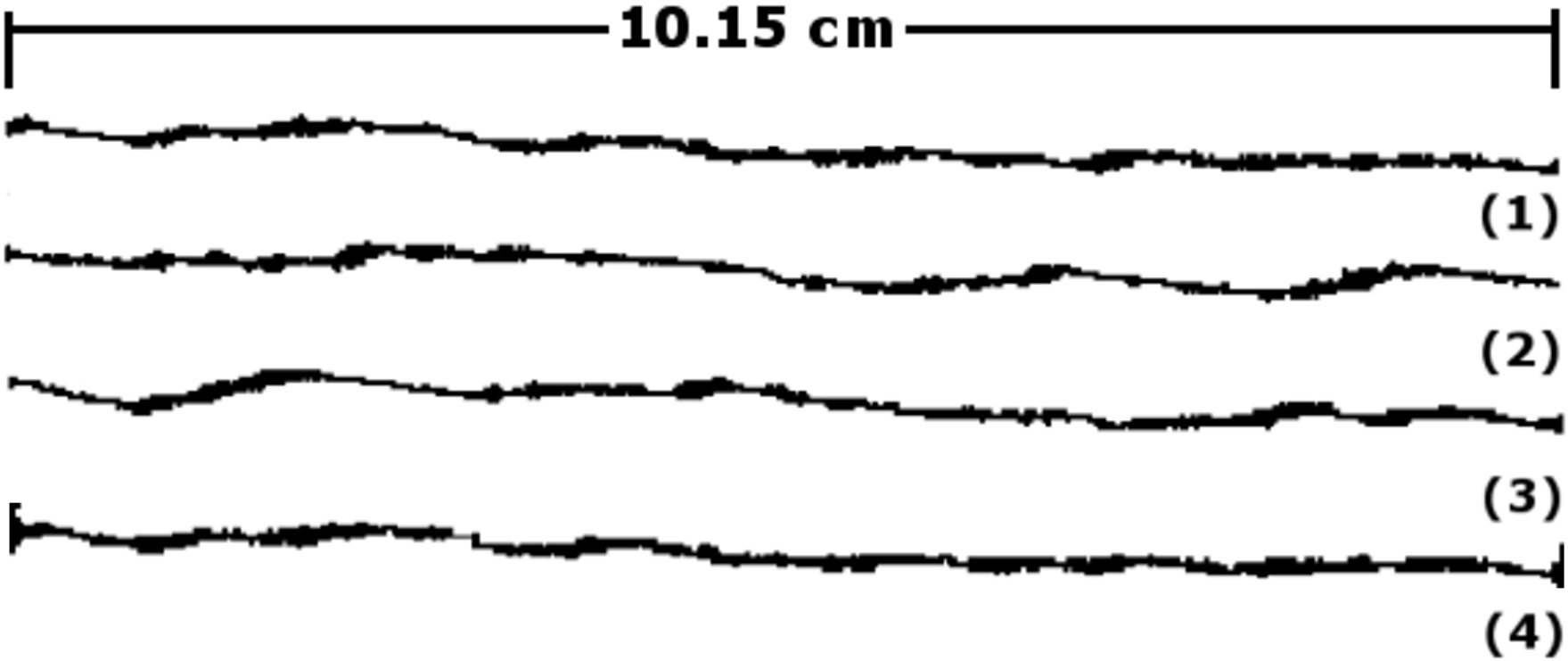
2-D Sections



Governing Equations

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Continuity

$$\frac{\partial U_j}{\partial x_j} = 0$$

Momentum

$$\frac{\partial}{\partial t} U_i + U_j \frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho} \frac{\partial P}{\partial x_i} + \nu \frac{\partial^2 U_i}{\partial x_j \partial x_j}$$

Frequency – Passage Width Distributions

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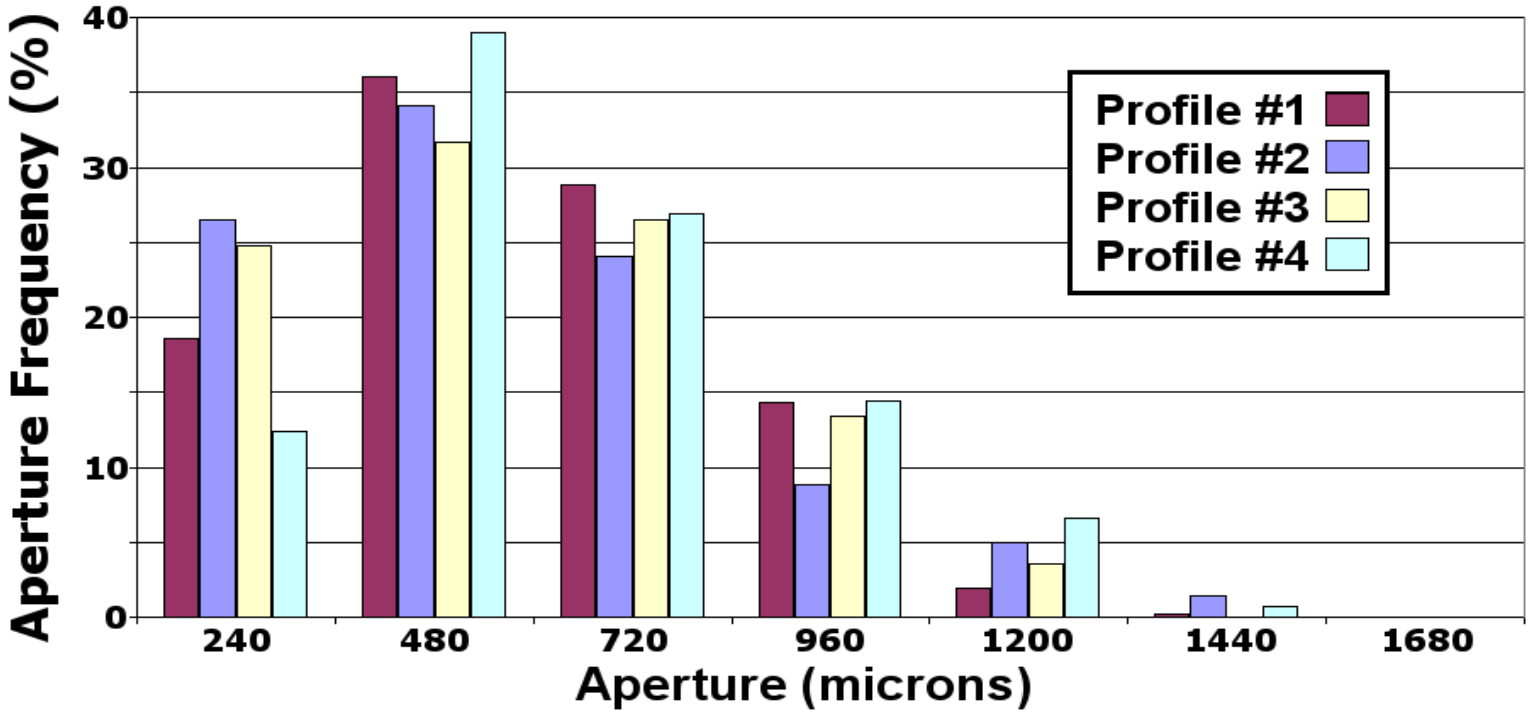
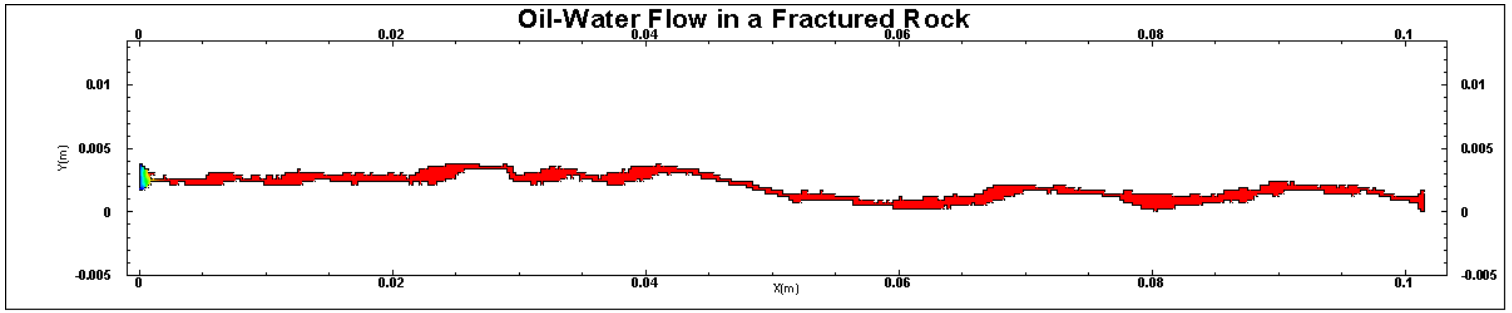


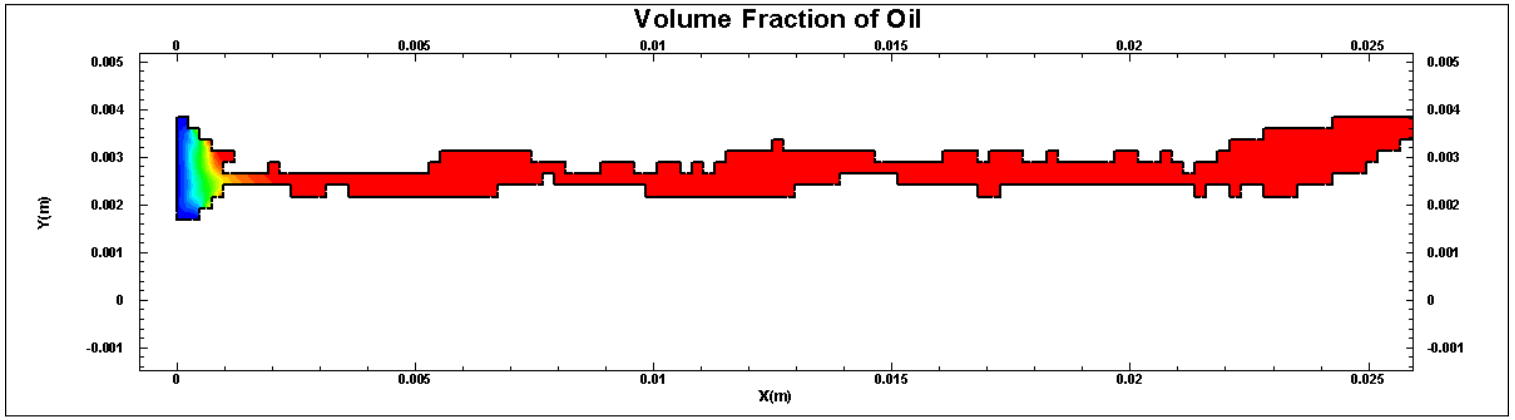
	h_{avg} (μm)	σ (μm)	Area (μm²)	D_f (-)	θ (%)
Profile #1	606	302	61.5	1.62	3.39
Profile #2	573	295	58.2	1.57	3.87
Profile #3	586	303	59.5	1.55	3.95
Profile #4	594	293	65.2	1.66	4.62

Water Flooding

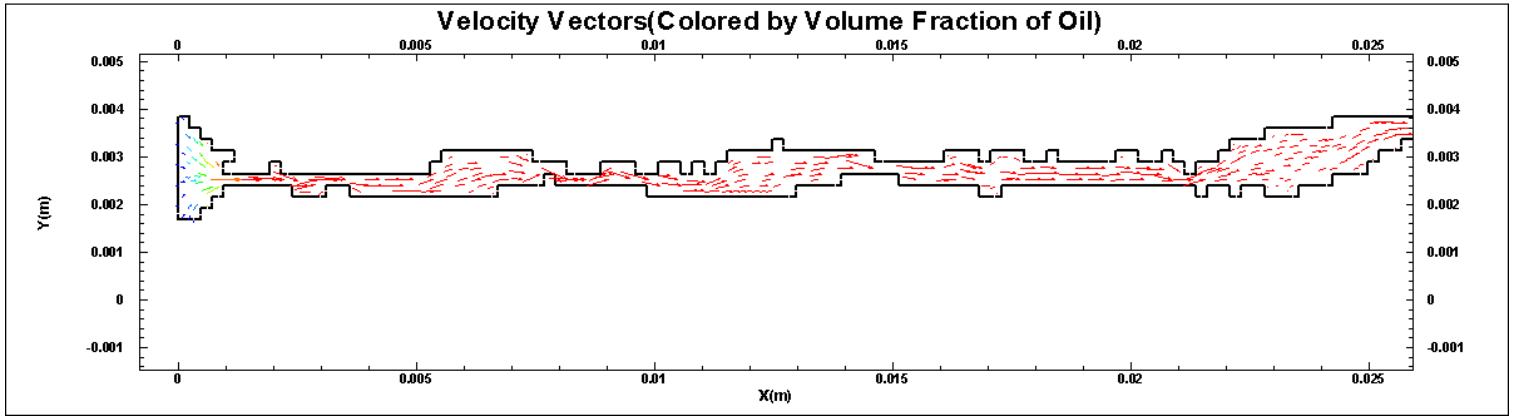
Impermeable Matrix



Water

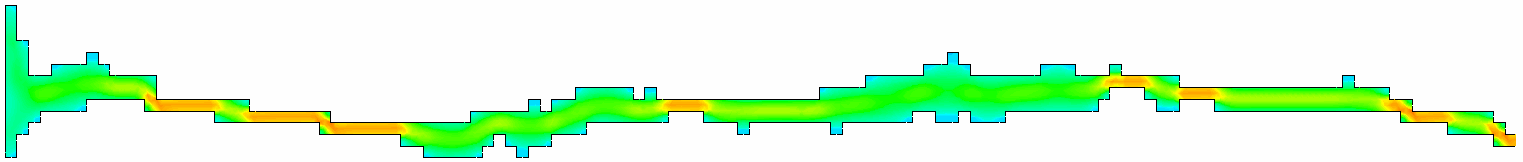


Oil

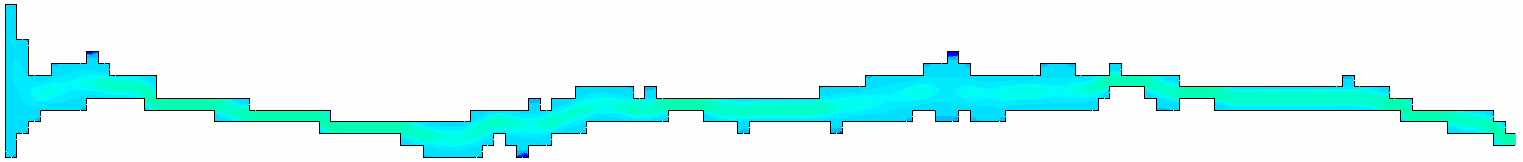


Velocity Magnitude Contours

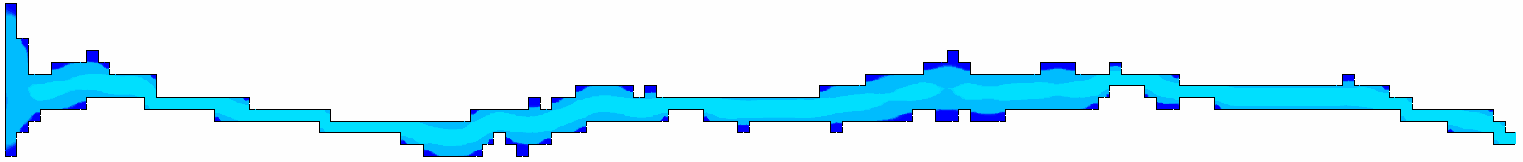
Air-Section (a)



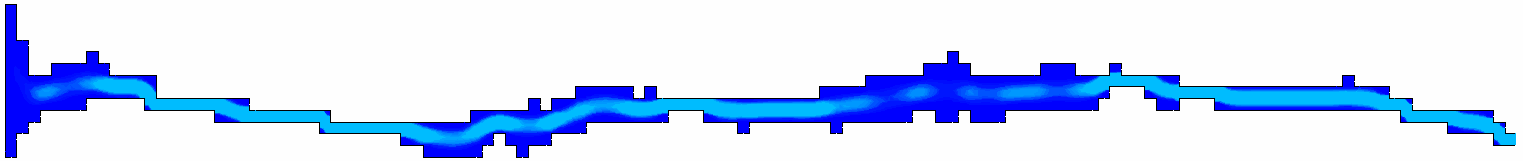
(iv) Flow Rate = 21.6 mm^2/s



(iii) Flow Rate = 1.44 mm^2/s



(ii) Flow Rate = 0.960 mm^2/s



(i) Flow Rate = 0.312 mm^2/s

Velocity Magnitude (mm/s): 0.04 4.92 47.18 99.36 163.46

Impermeable Matrix

% Flow Through Fracture

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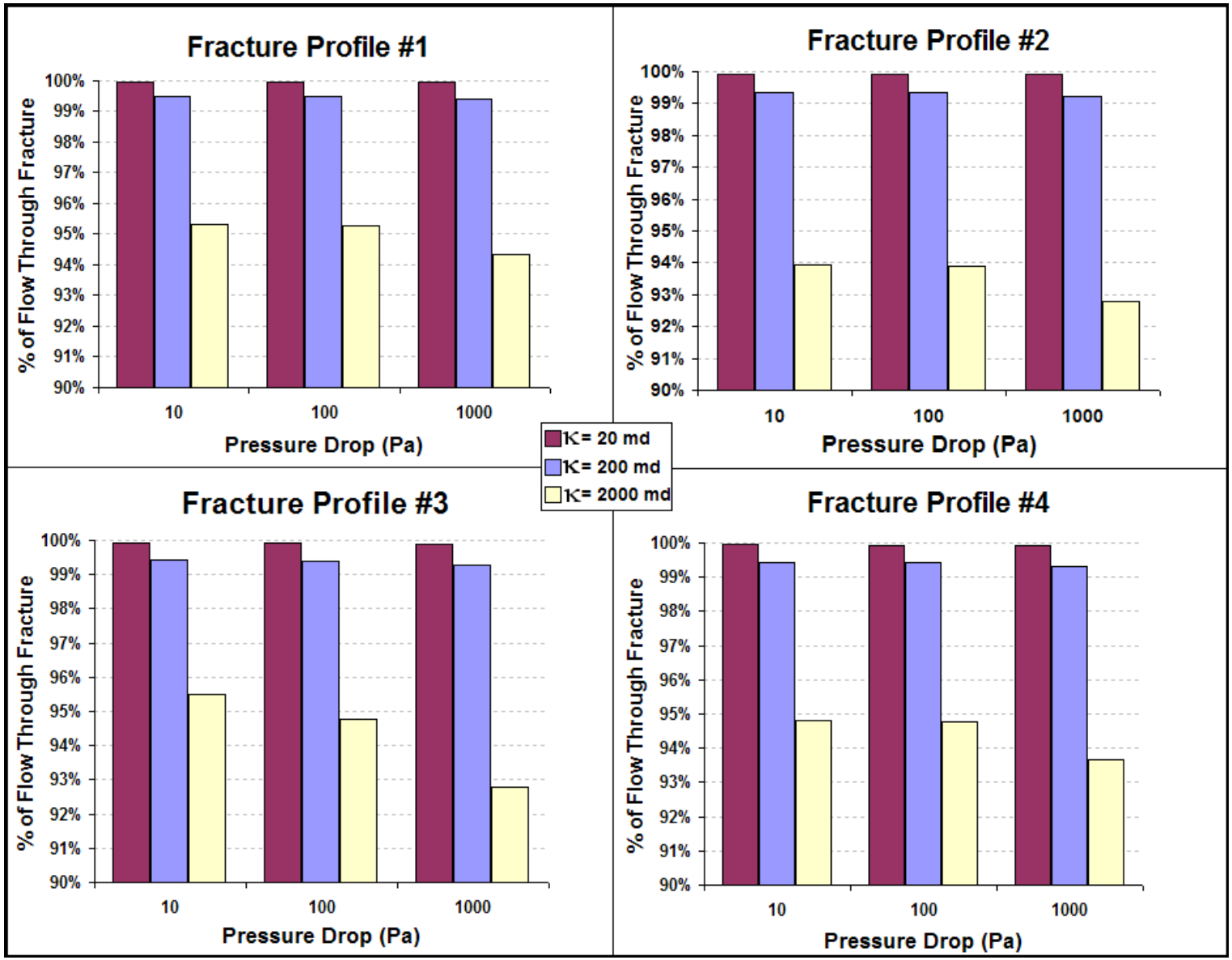

Fracture Cell

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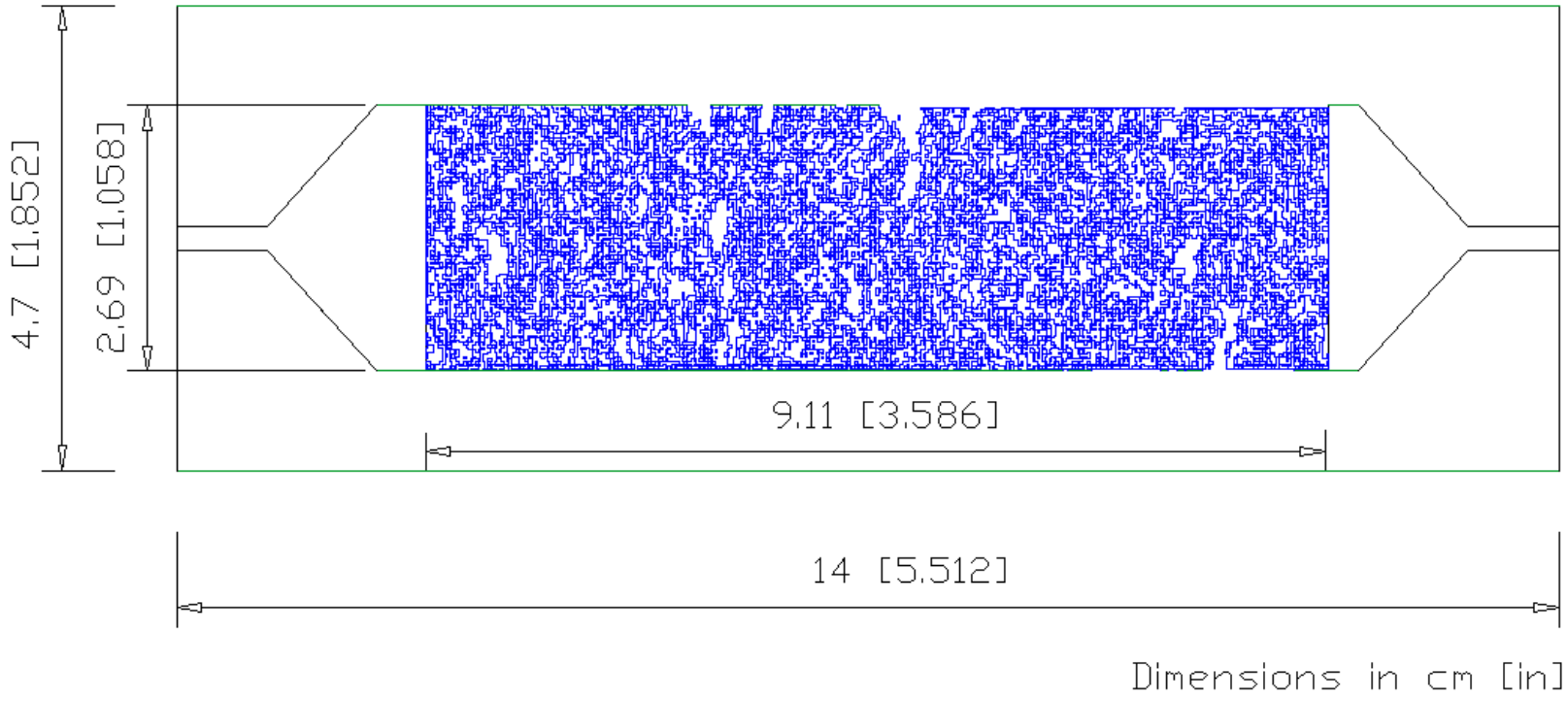
Using in-house code the ASCII 240 micron data was converted to 'flattened' fracture model.

Stereolithography (STL) was used to create the model from DSM Somos 11120 STL Resin.



Fracture Cell

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Experimental Conditions

- Model outlet open to atmosphere
- Room Temperature
- Flow Direction
  - A to B (AB)
  - B to A (BA)

- Constant Volumetric Flow Rate (14 different)
  - $0.001 < Q(^{ml}/_{min}) < 15$
  - $9.5(10^{-9}) < Ca < 1.4(10^{-4})$
  - $0.0173 < v_{darcy}\ (^{m}/_{day}) < 260$

Air - Water

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Q=0.5ml/min

Air

Q=10ml/min

Breakthrough Images (AB)

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- Q 10 $^{ml}/_{min}$ v_{darcy} 173 $^{m}/_{day}$

- Q 1.0 $^{ml}/_{min}$ v_{darcy} 17.3 $^{m}/_{day}$

- Q 0.1 $^{ml}/_{min}$ v_{darcy} 1.73 $^{m}/_{day}$

- Q 0.01 $^{ml}/_{min}$ v_{darcy} 0.17 $^{m}/_{day}$

Fractal Dimension

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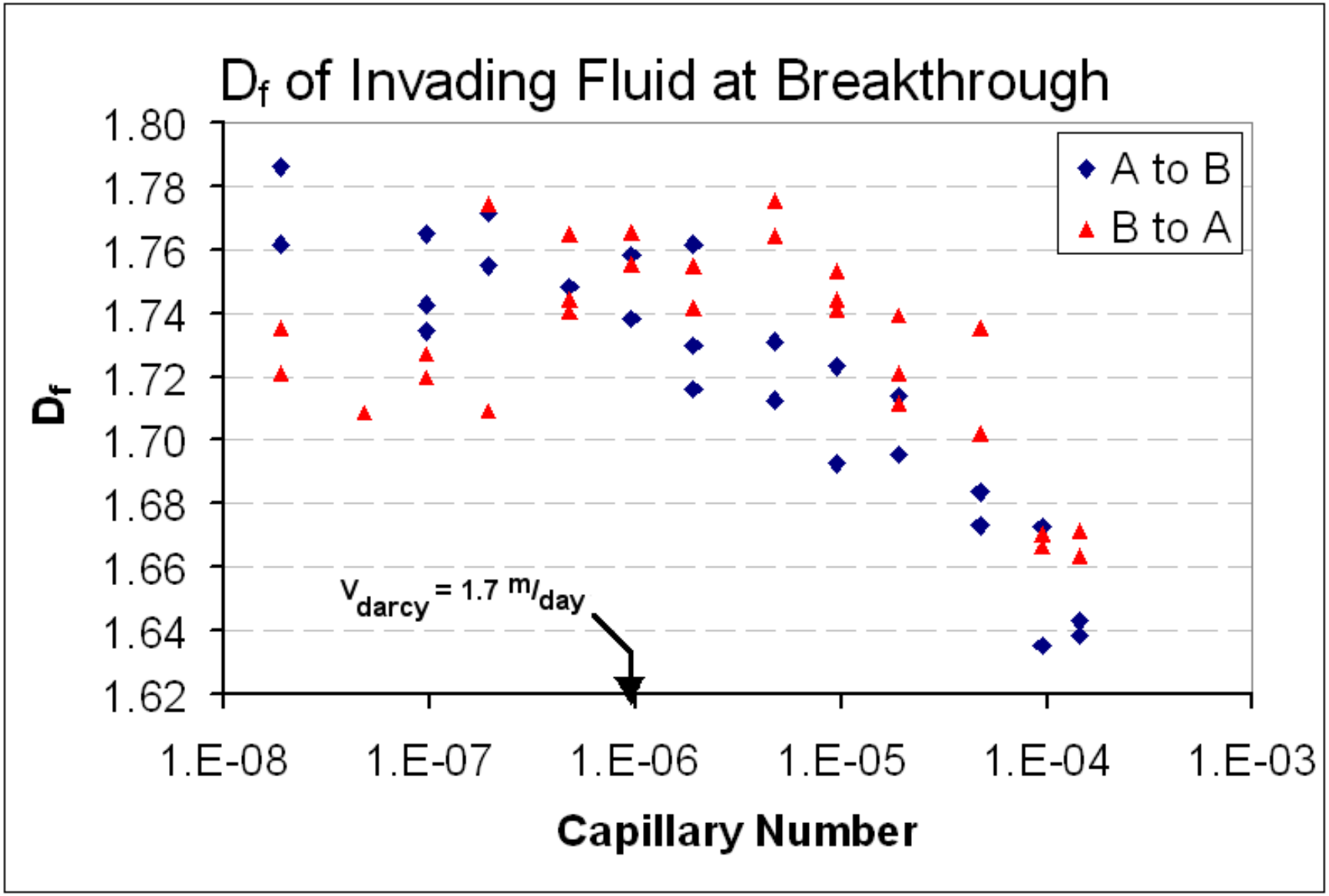

Fluid Saturation

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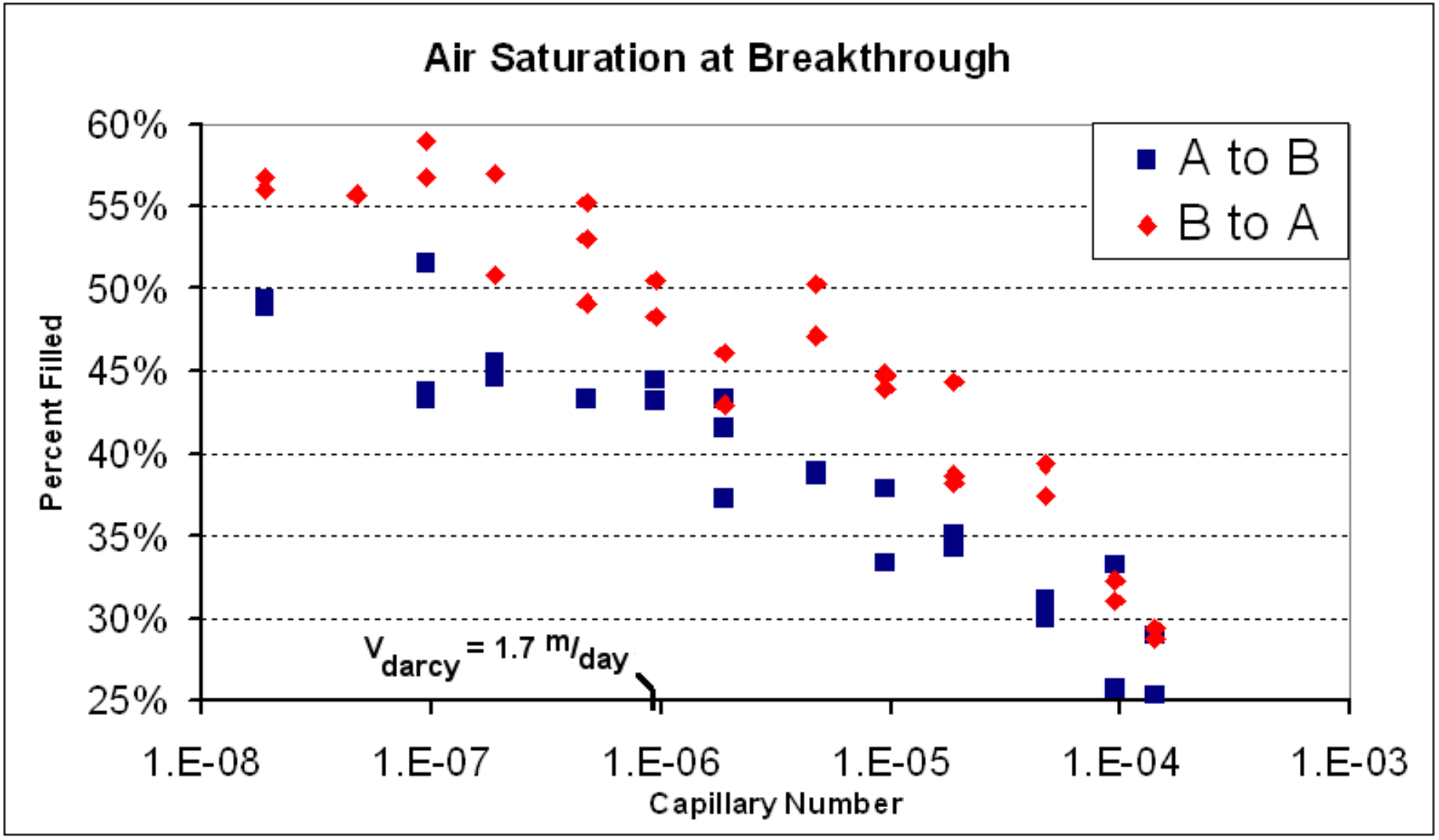

Computational Grid – 3D

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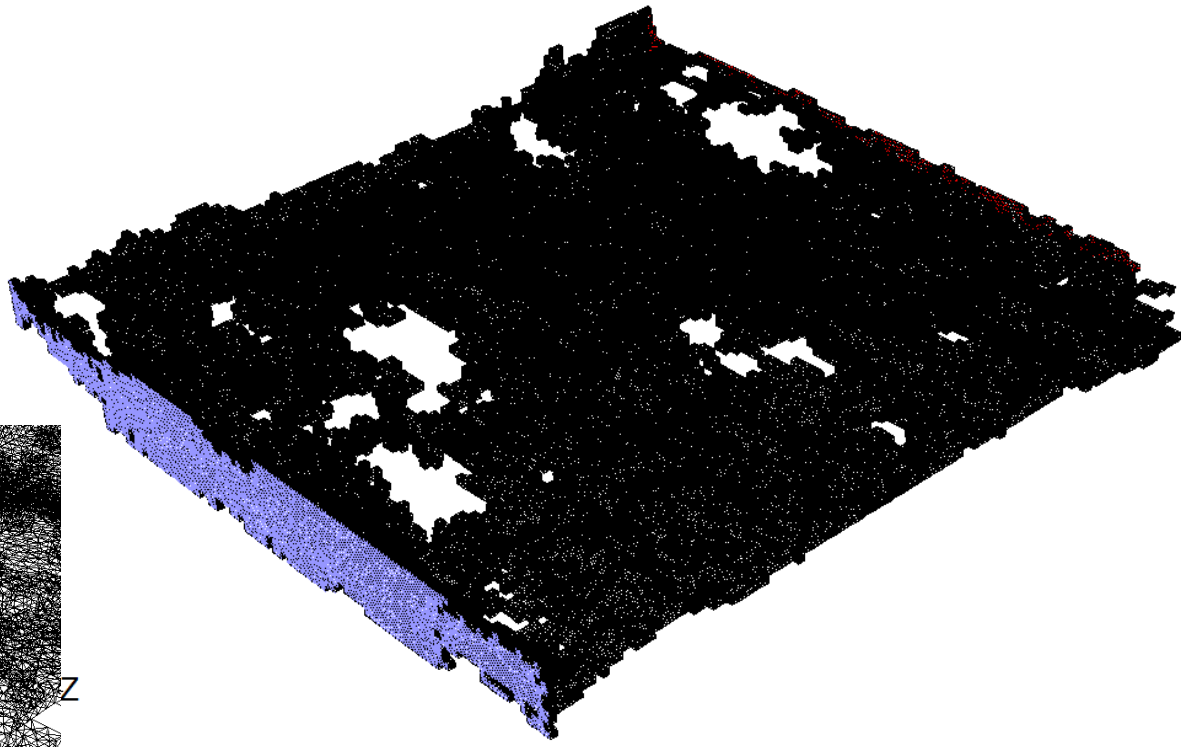

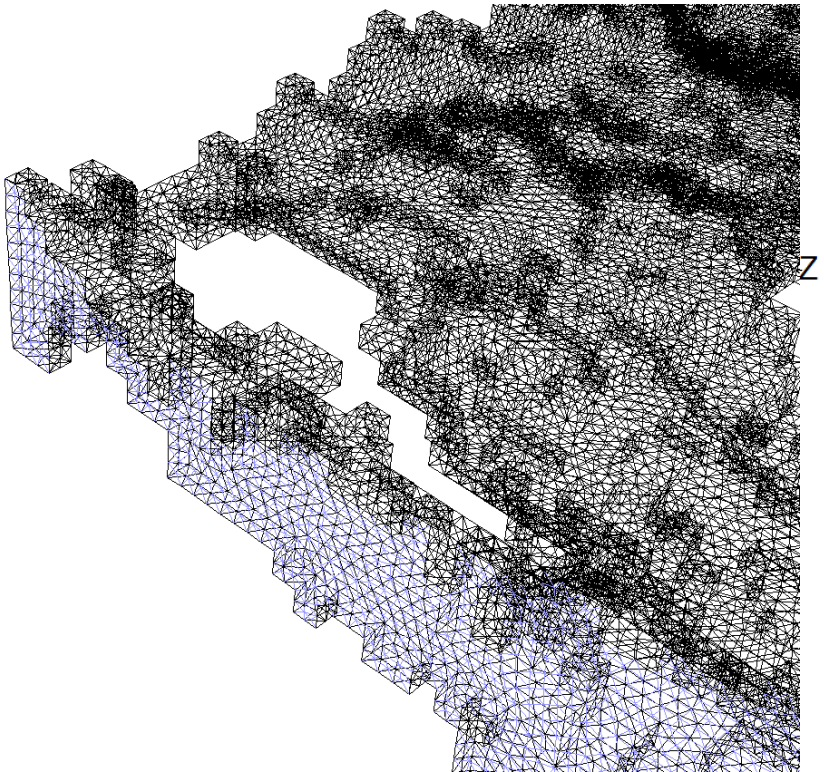

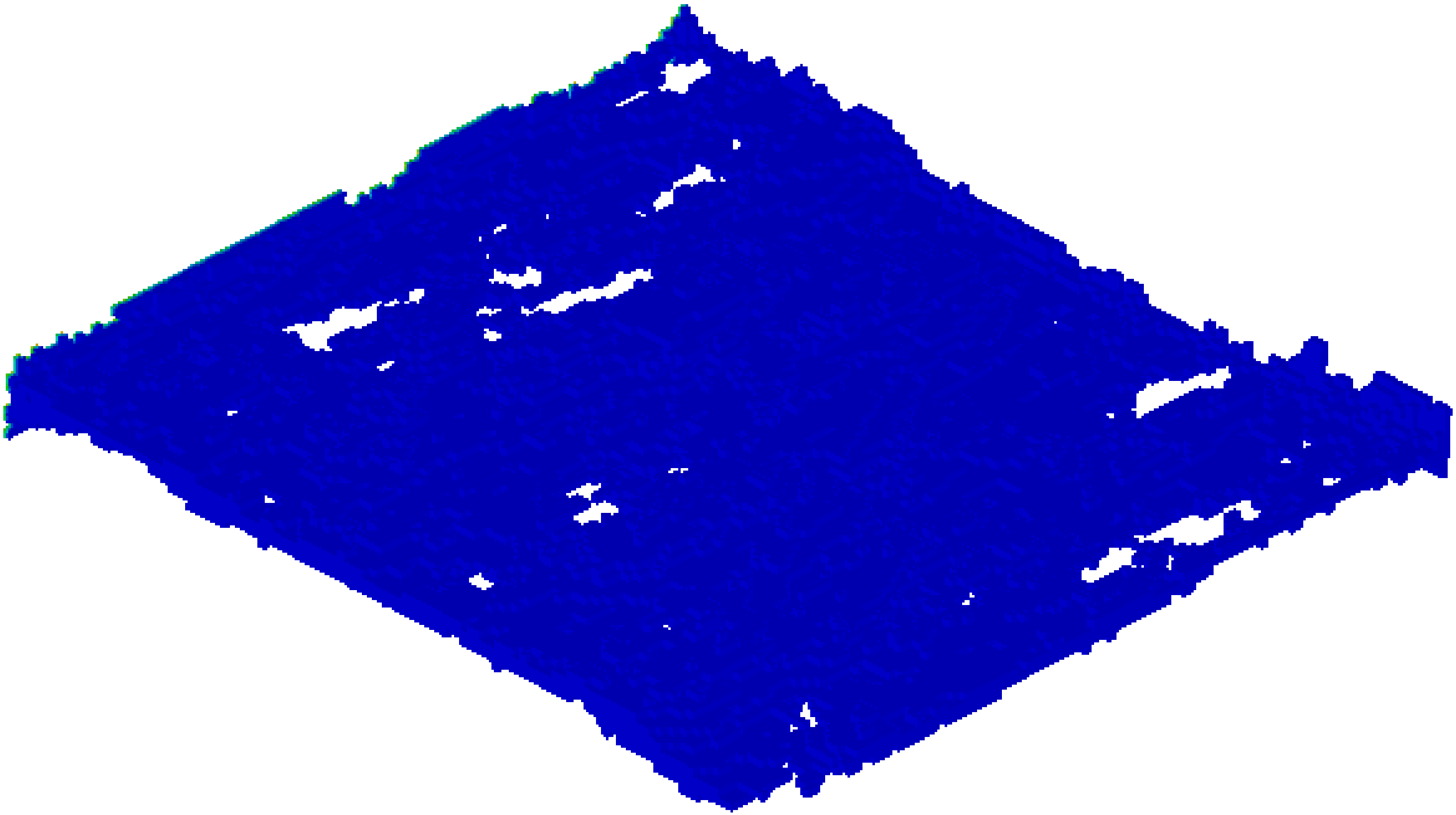

Air - Water

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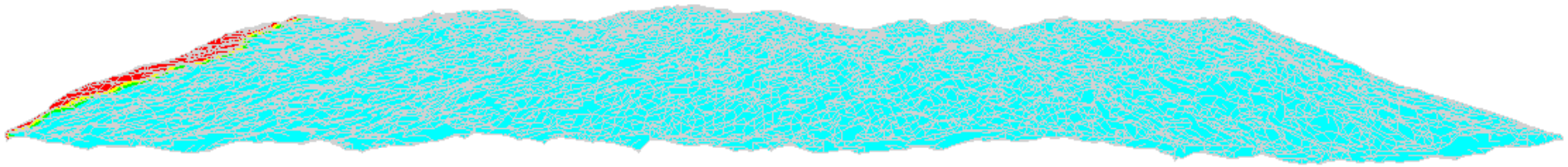
Air → **Water**



Fracture Flow under Confining Pressure

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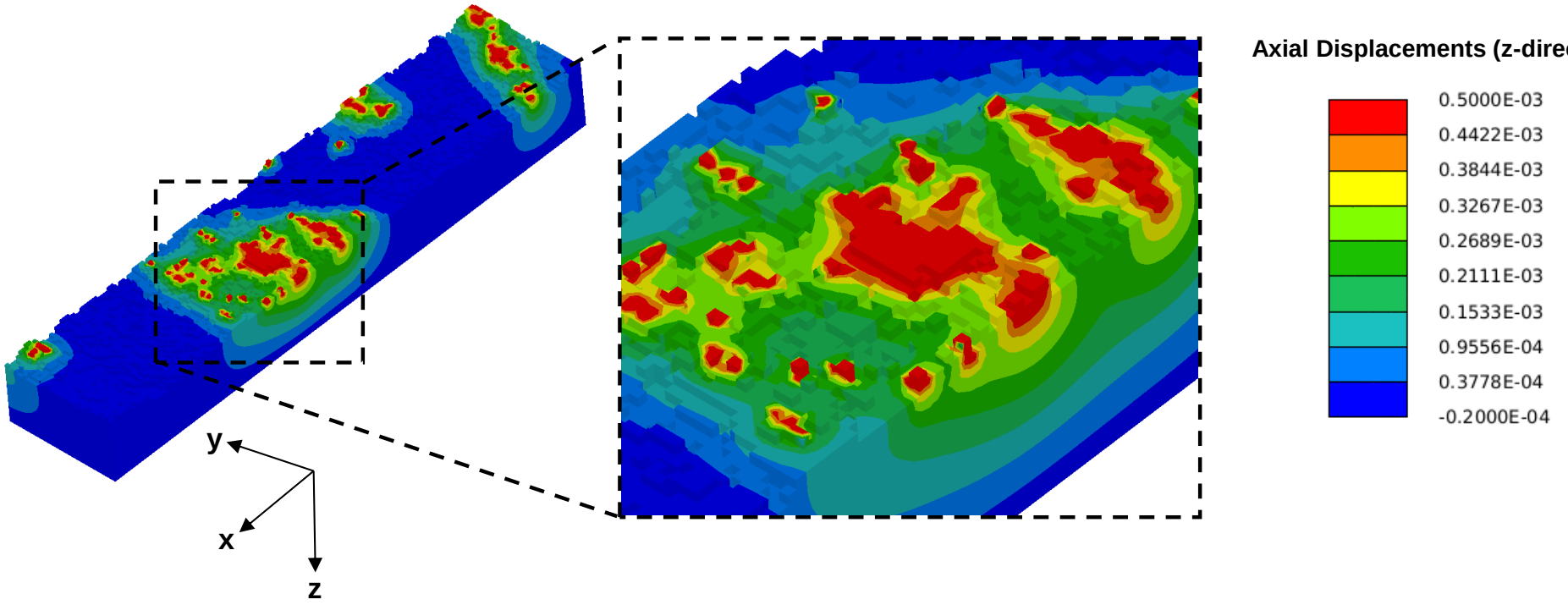
Roman, Ahmadi, and Issen



Fracture Flow under Confining Pressure

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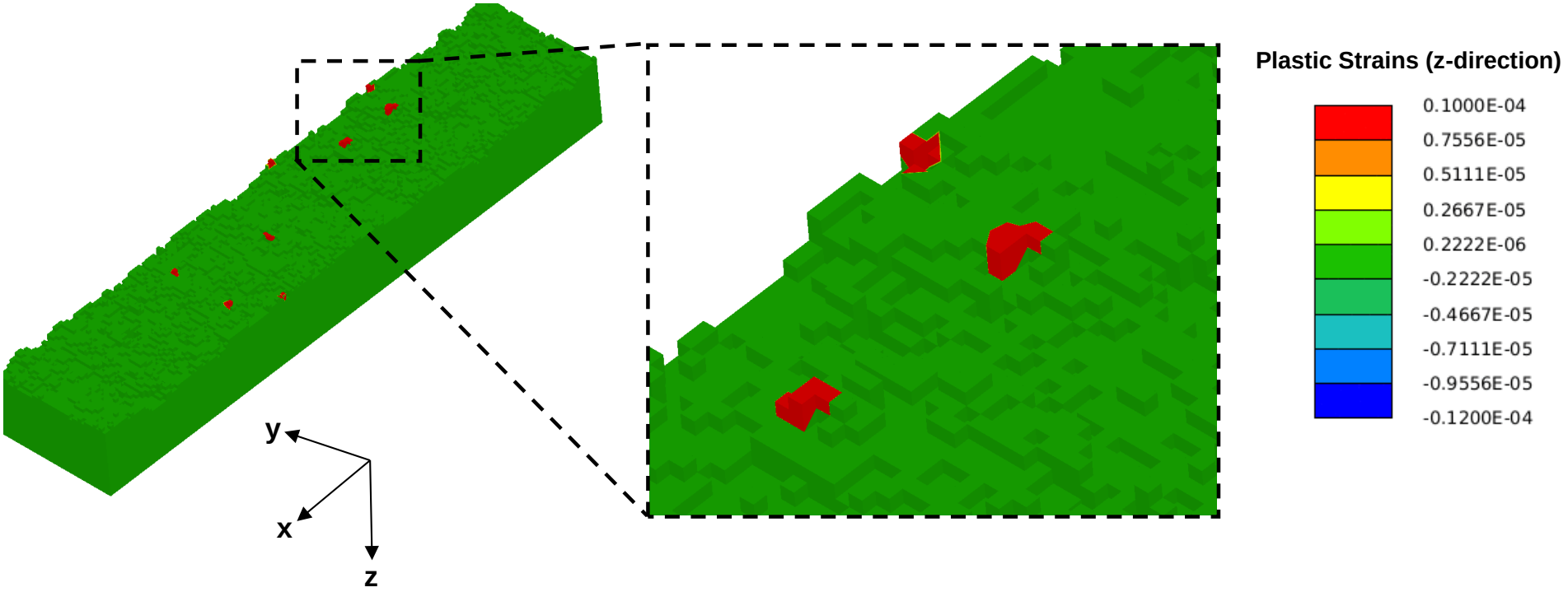
Roman, Ahmadi, and Issen



Fracture Flow under Confining Pressure

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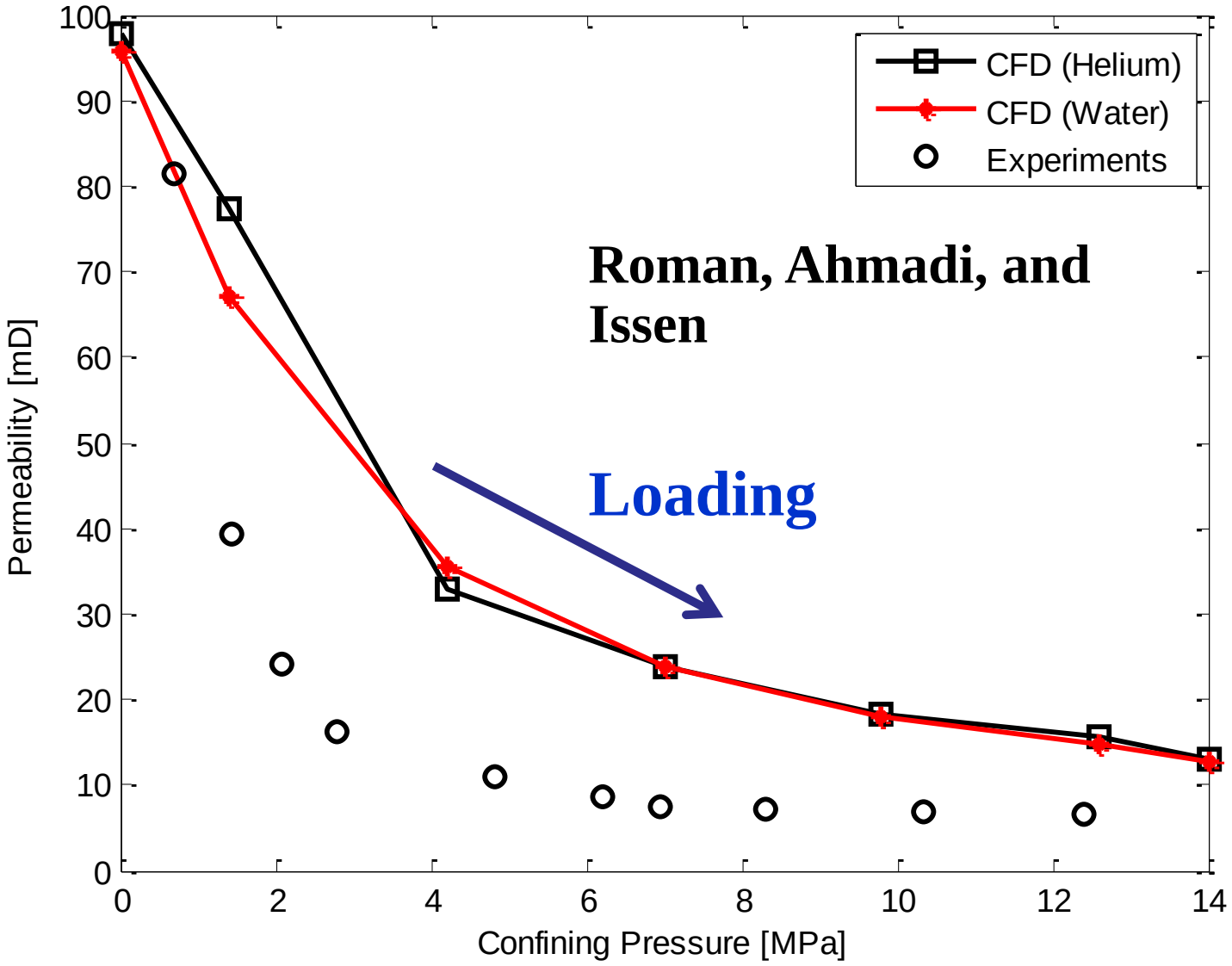

Proppant Transport in Fractures

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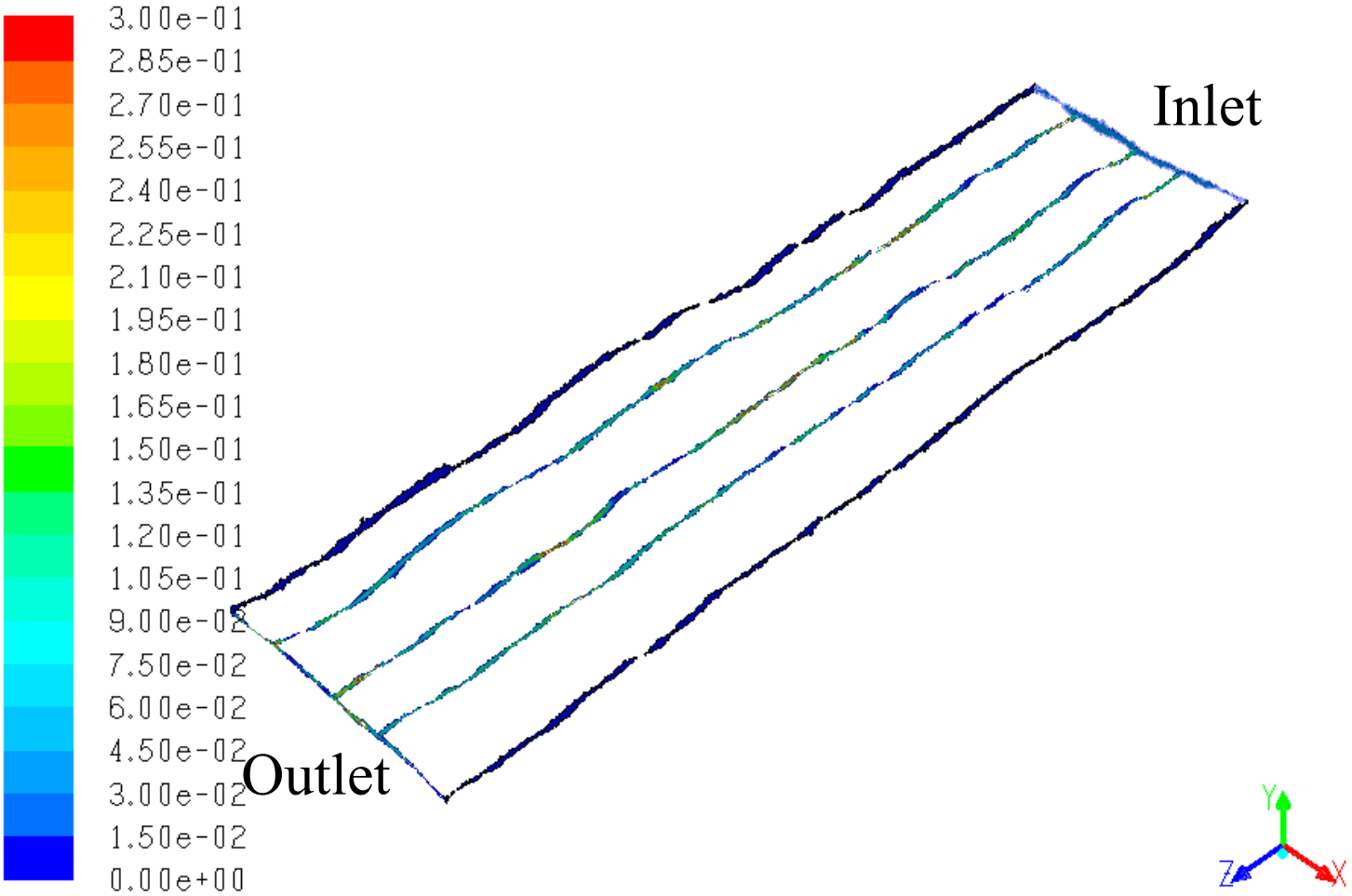

Velocity magnitude contours (m/s) (V_{in} = 6cm/s)

Proppant Transport in Fractures

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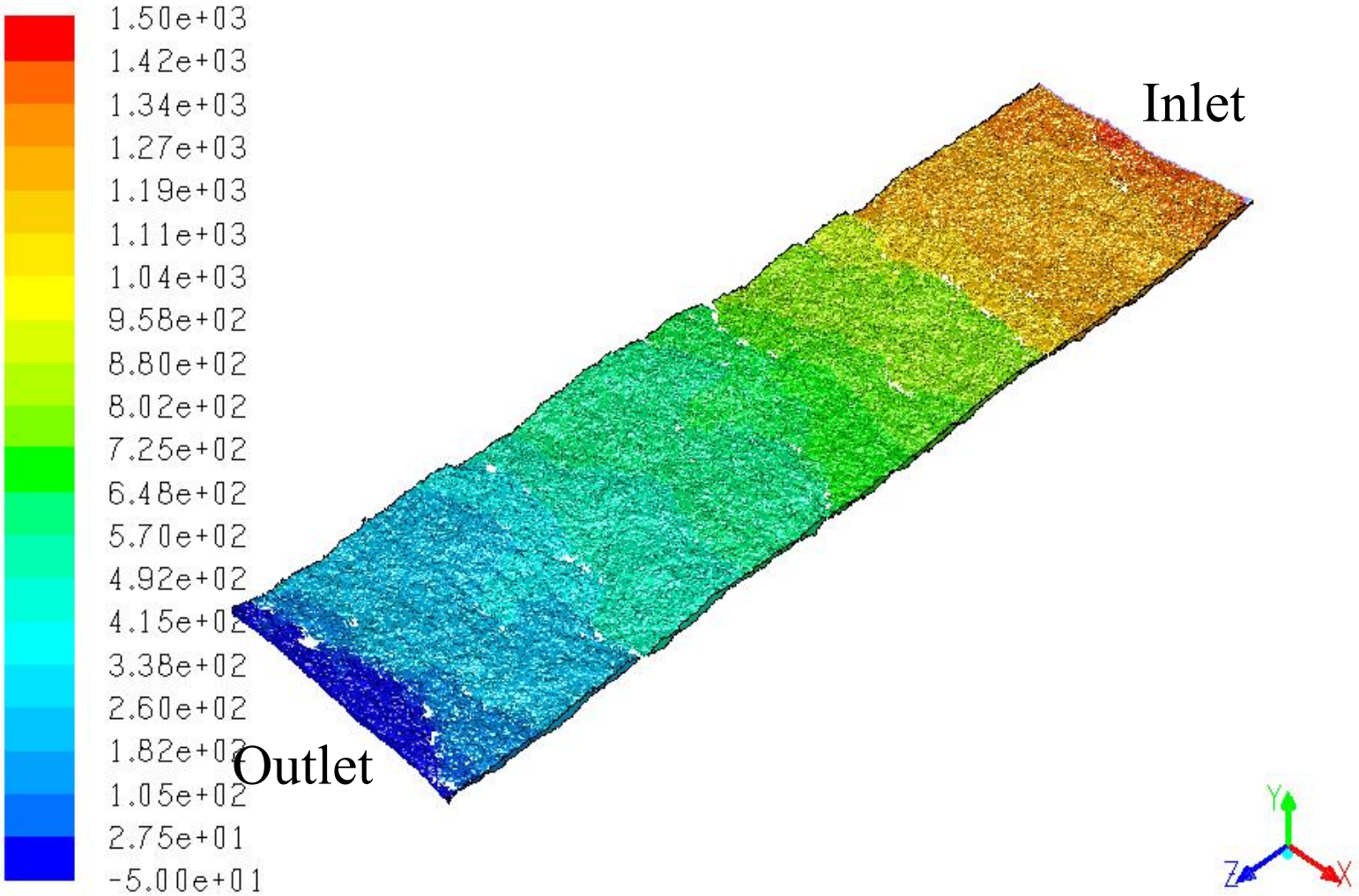

Static pressure contours (Pascal) (V_{in} = 6cm/s)

Proppant Transport in Fractures

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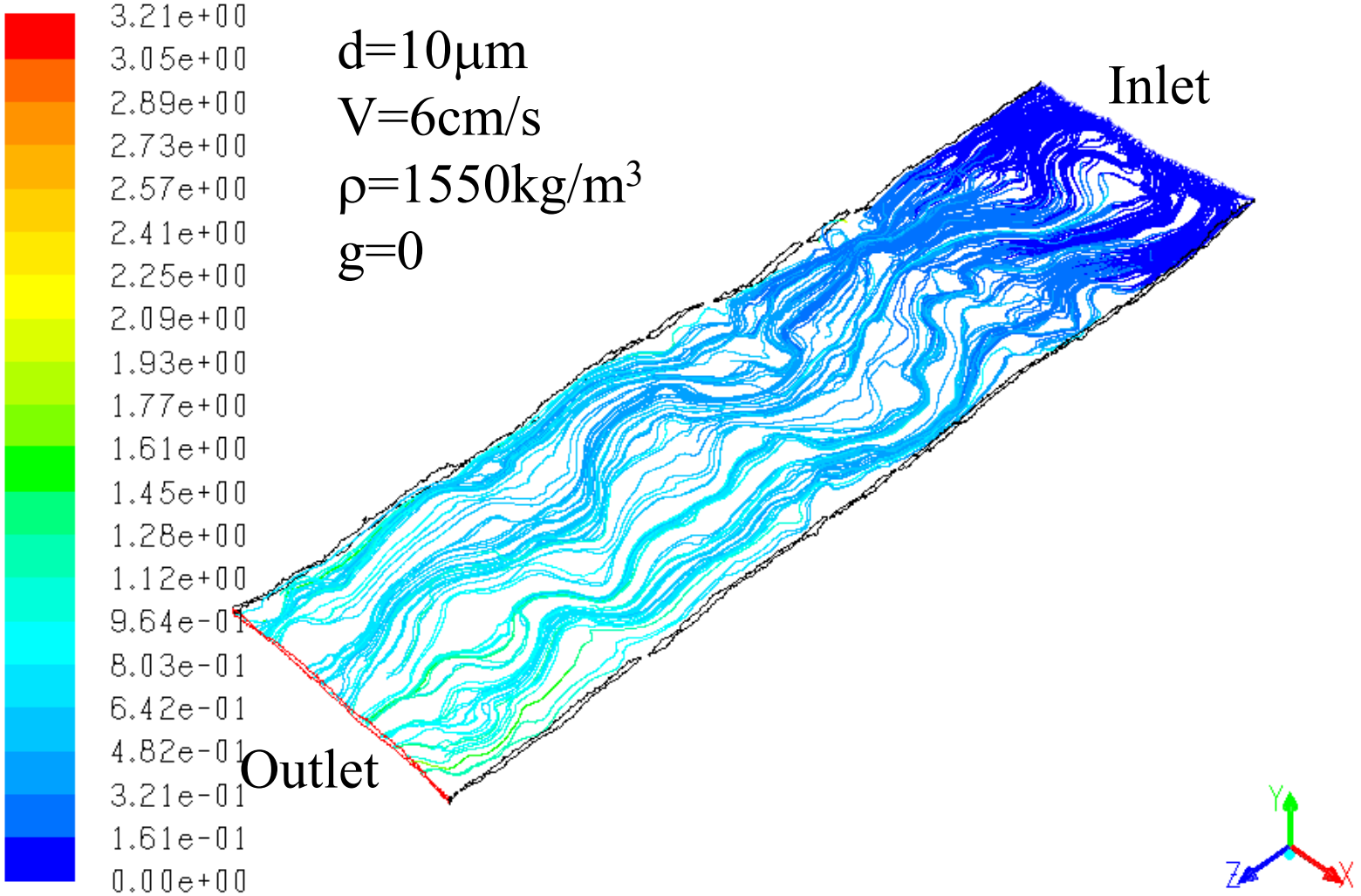

Particle trajectories colored by particle residence time (s) (V_{in} = 6cm/s)

Proppant Transport in Fractures

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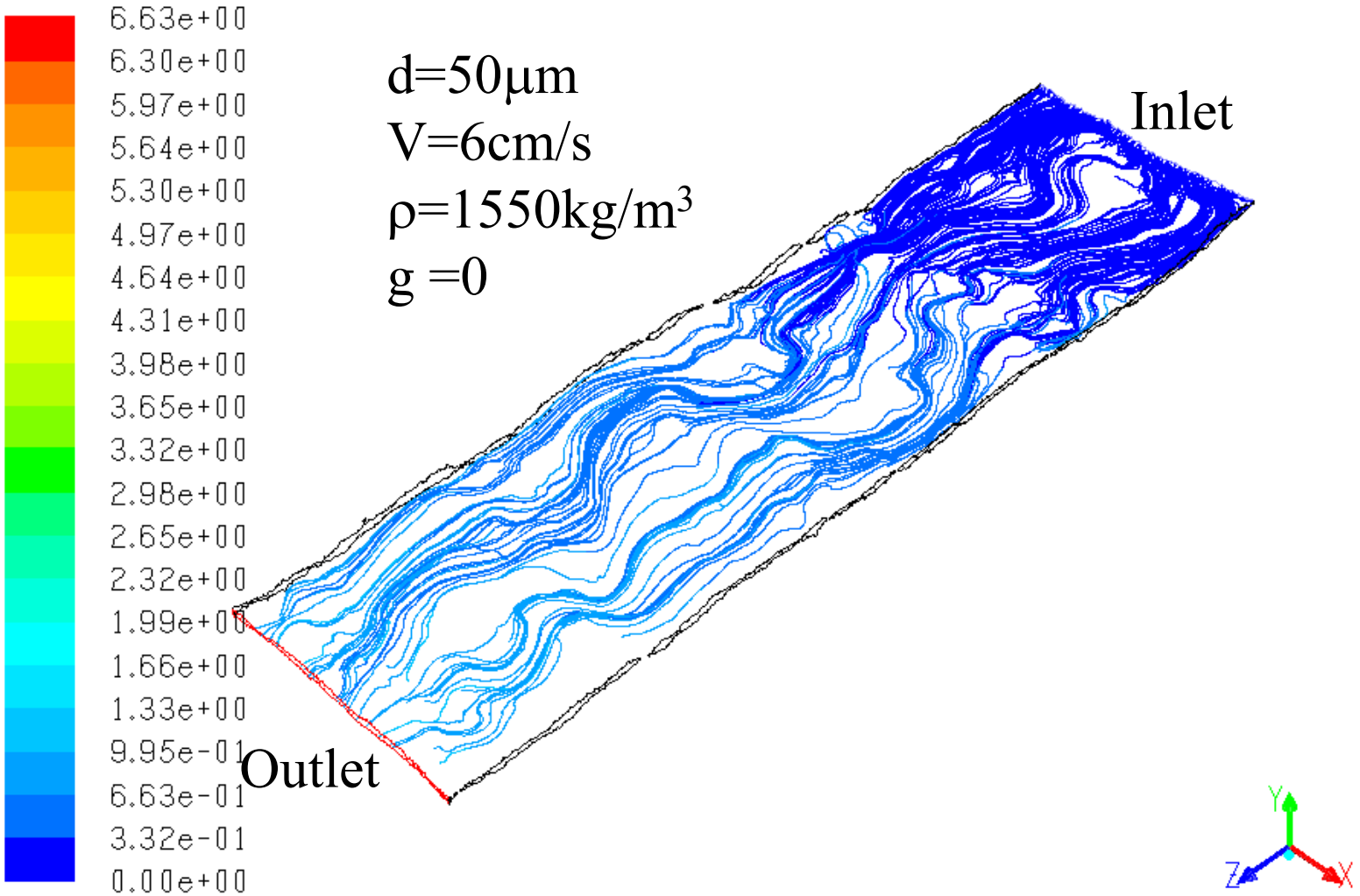

Particle trajectories colored by particle residence time (s) (V_{in} = 6cm/s)

Proppant Transport in Fractures

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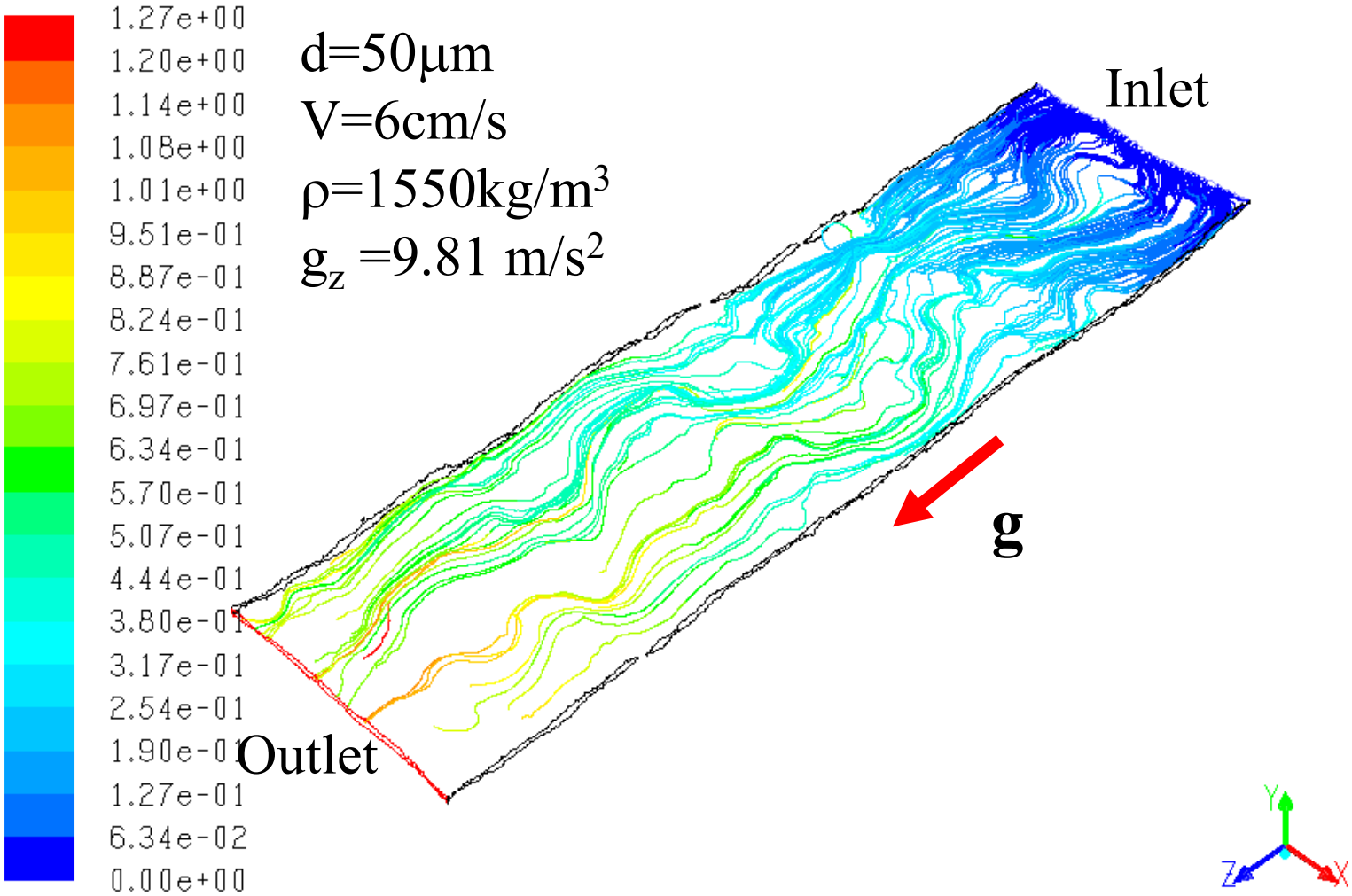

Particle trajectories colored by particle residence time (s) (V_{in} = 6cm/s)

Proppant Transport in Fractures

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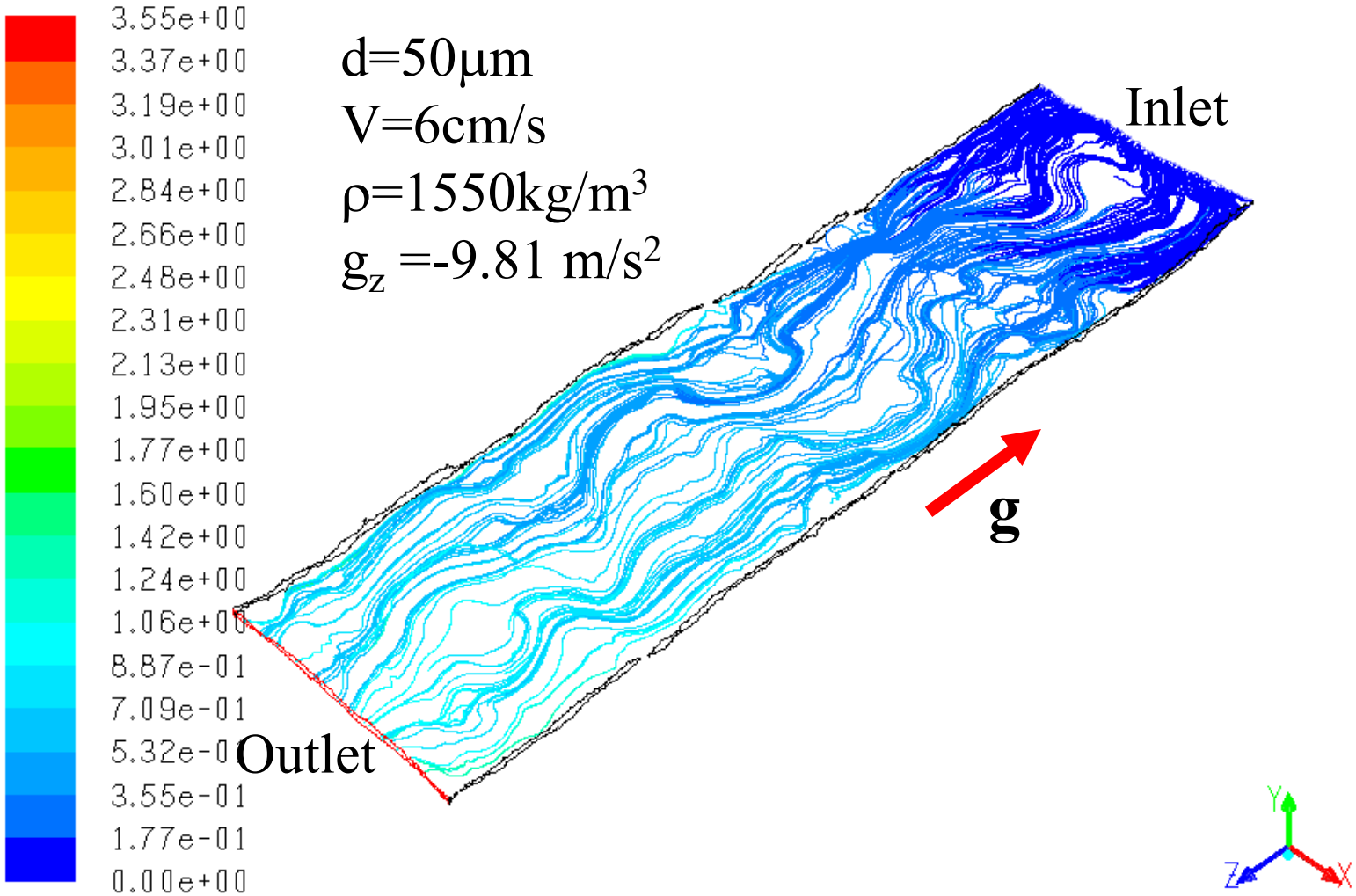

Particle trajectories colored by particle residence time (s) (V_{in} = 6cm/s)

Proppant Transport in Fractures

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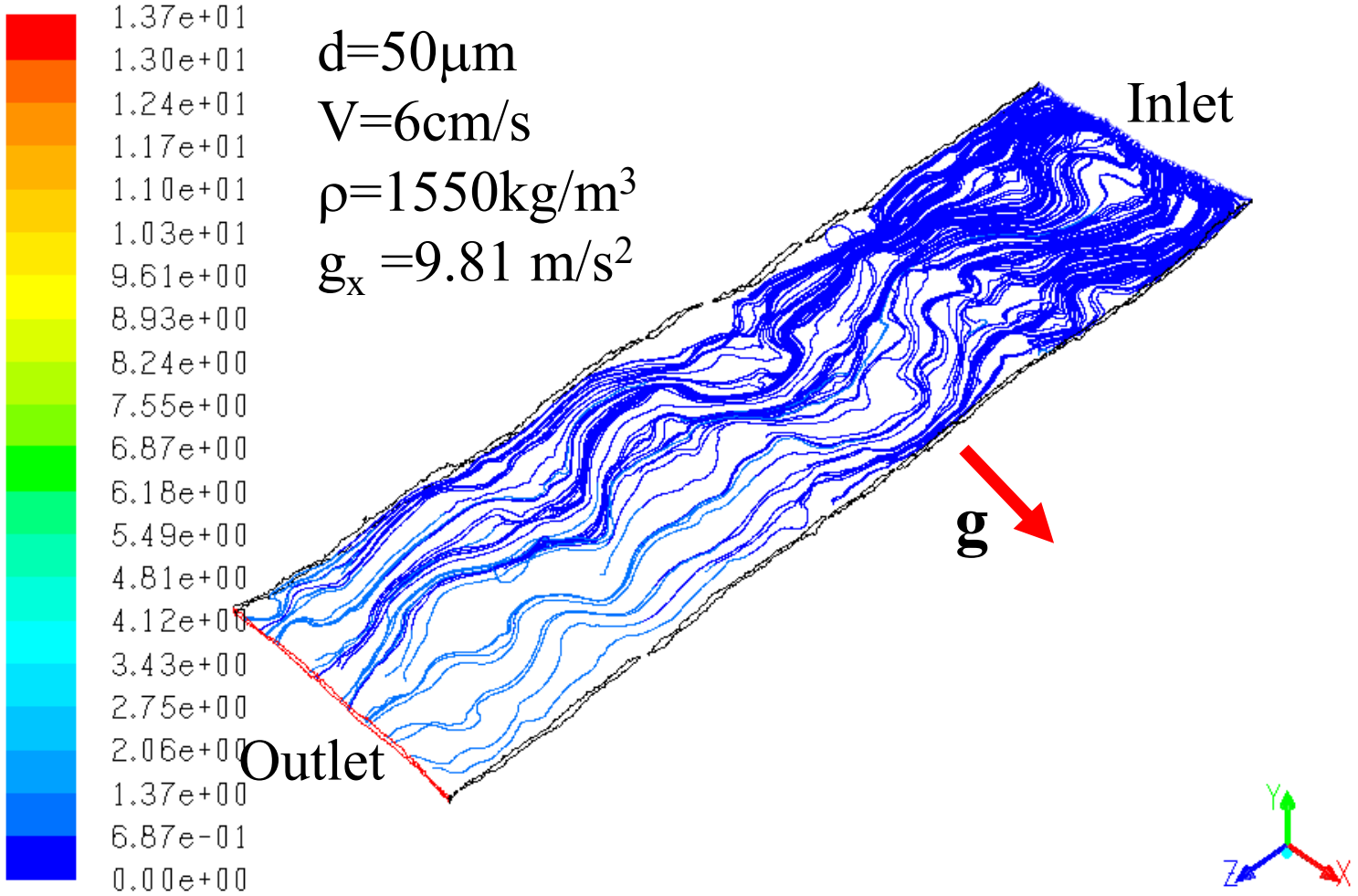

Particle trajectories colored by particle residence time (s) (V_{in} = 6cm/s)

Proppant Transport in Fractures

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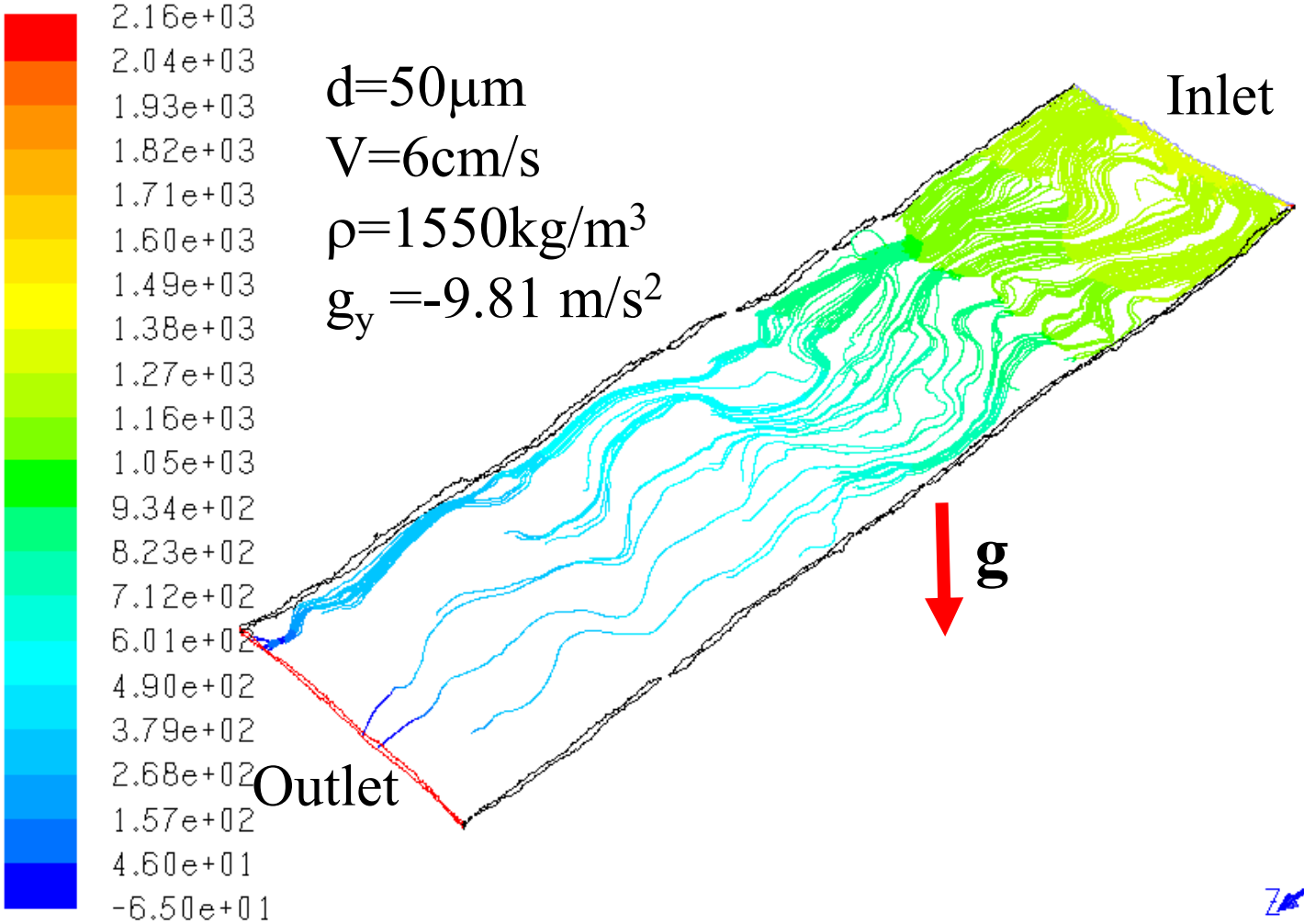

Particle trajectories colored by static pressure(Pascal) (V_{in} = 6cm/s)

Proppant Transport in Fractures

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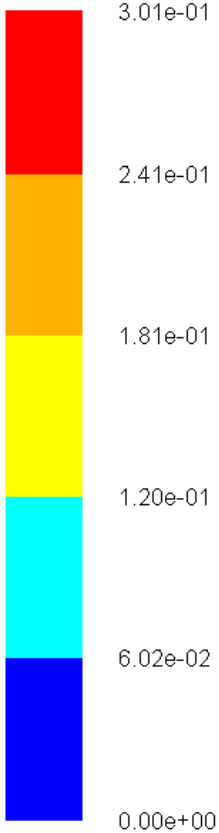
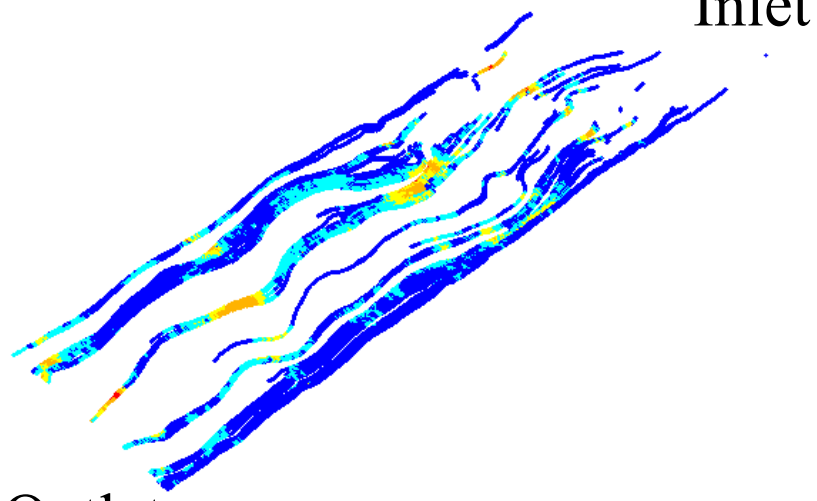
d=50μm
V=6cm/s
ρ=1550kg/m^3
g =0 m/s^2

For two-way coupled
2000 particles are injected
At dt=0.001s
Volume fraction=5.4x10^{-5}





	Total	Escaped	Trapped	Pertentage Captured
one-way	8912000	372002	8539998	0.958
two-way	8912000	364476	8547524	0.959

Particle trajectories colored by velocity magnitude

Proppant Deposition in Fractures

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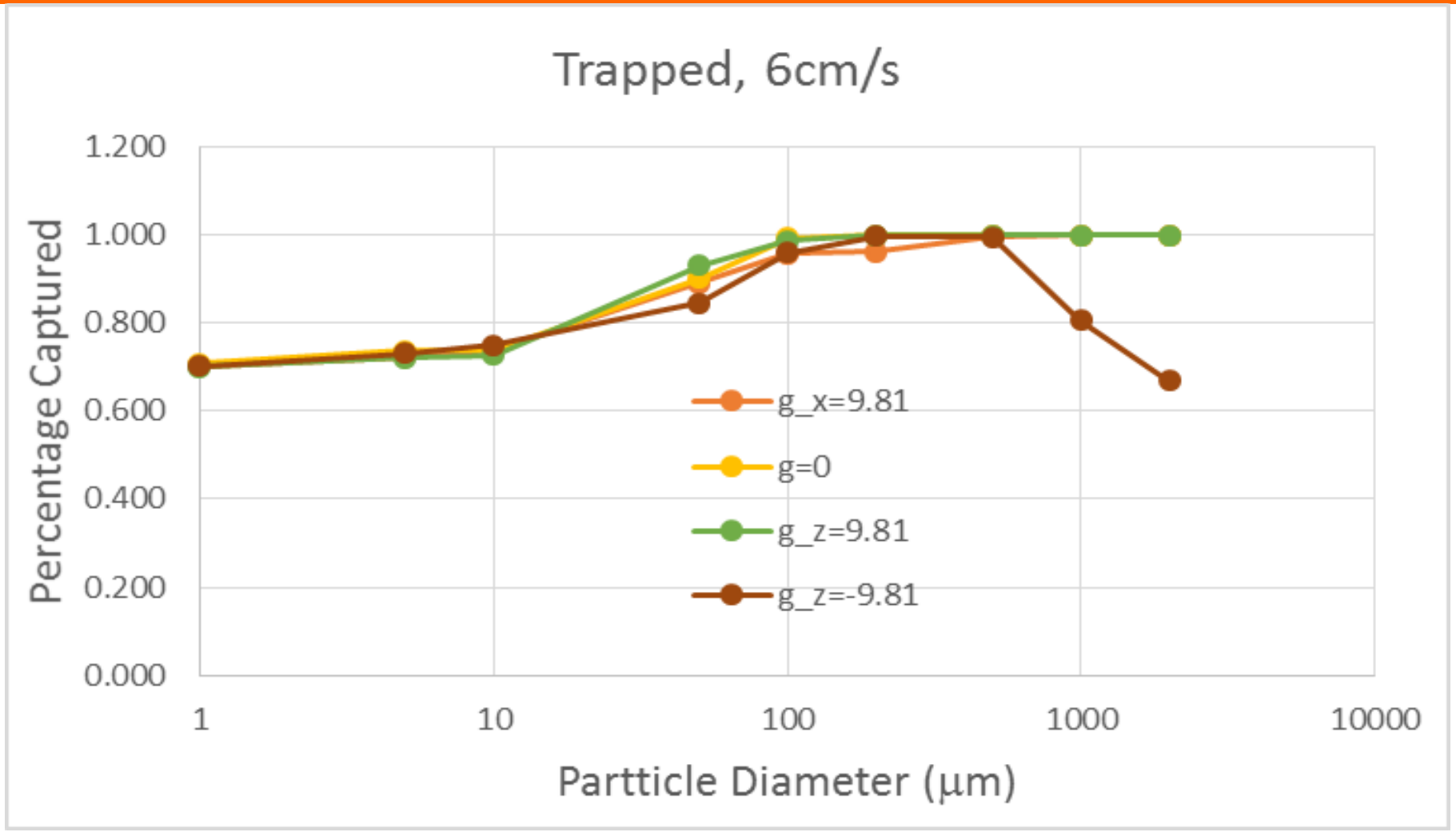

Capture efficiency versus particle diameter. Effect of gravity direction (V_{in} = 6cm/s, V_{inp} = 6cm/s)

Proppant Deposition in Fractures

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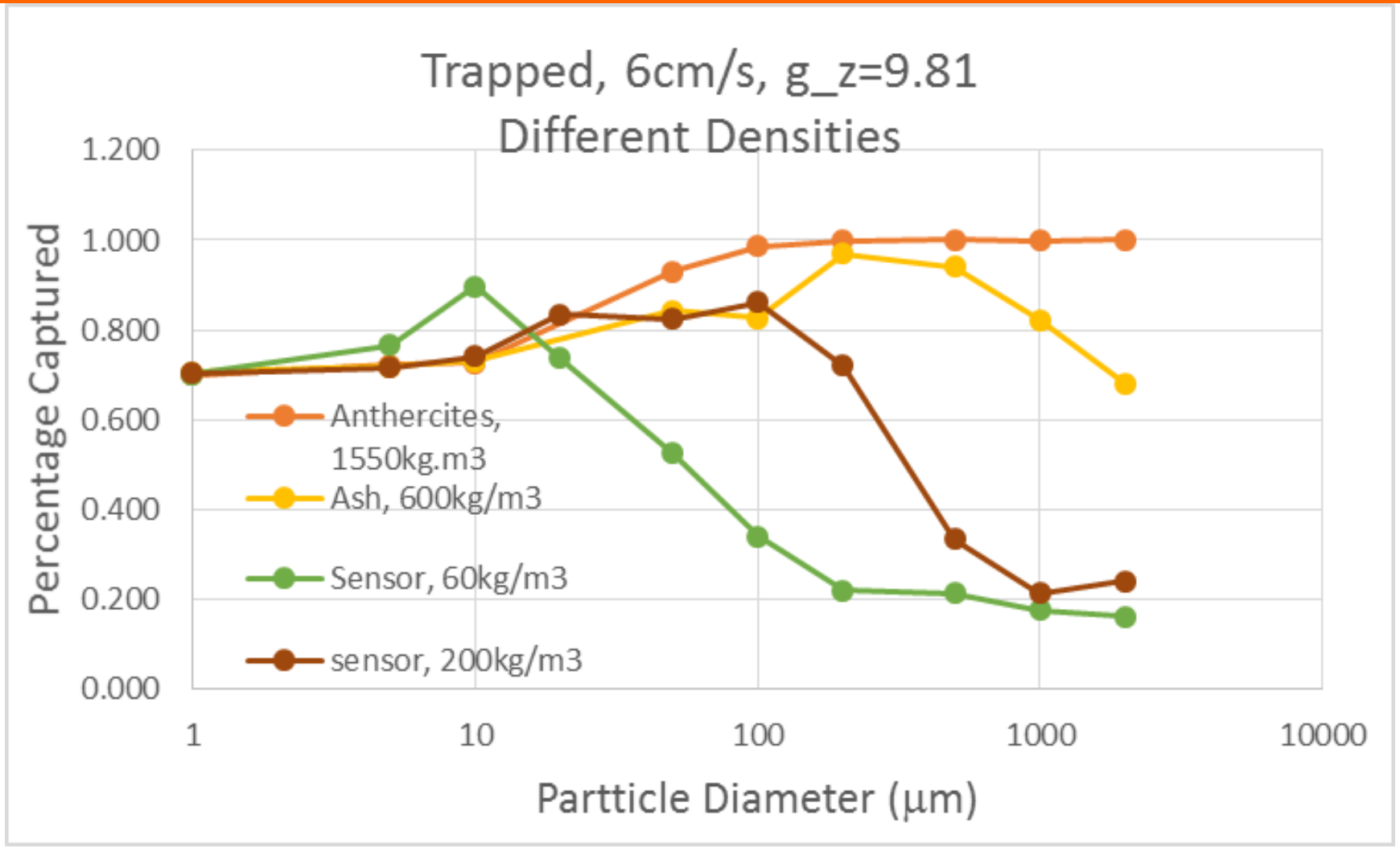

Capture efficiency versus particle diameter. Effect of particle density.
(V_{in} = 6cm/s, g_z=9.81)

Proppant Deposition in Fractures

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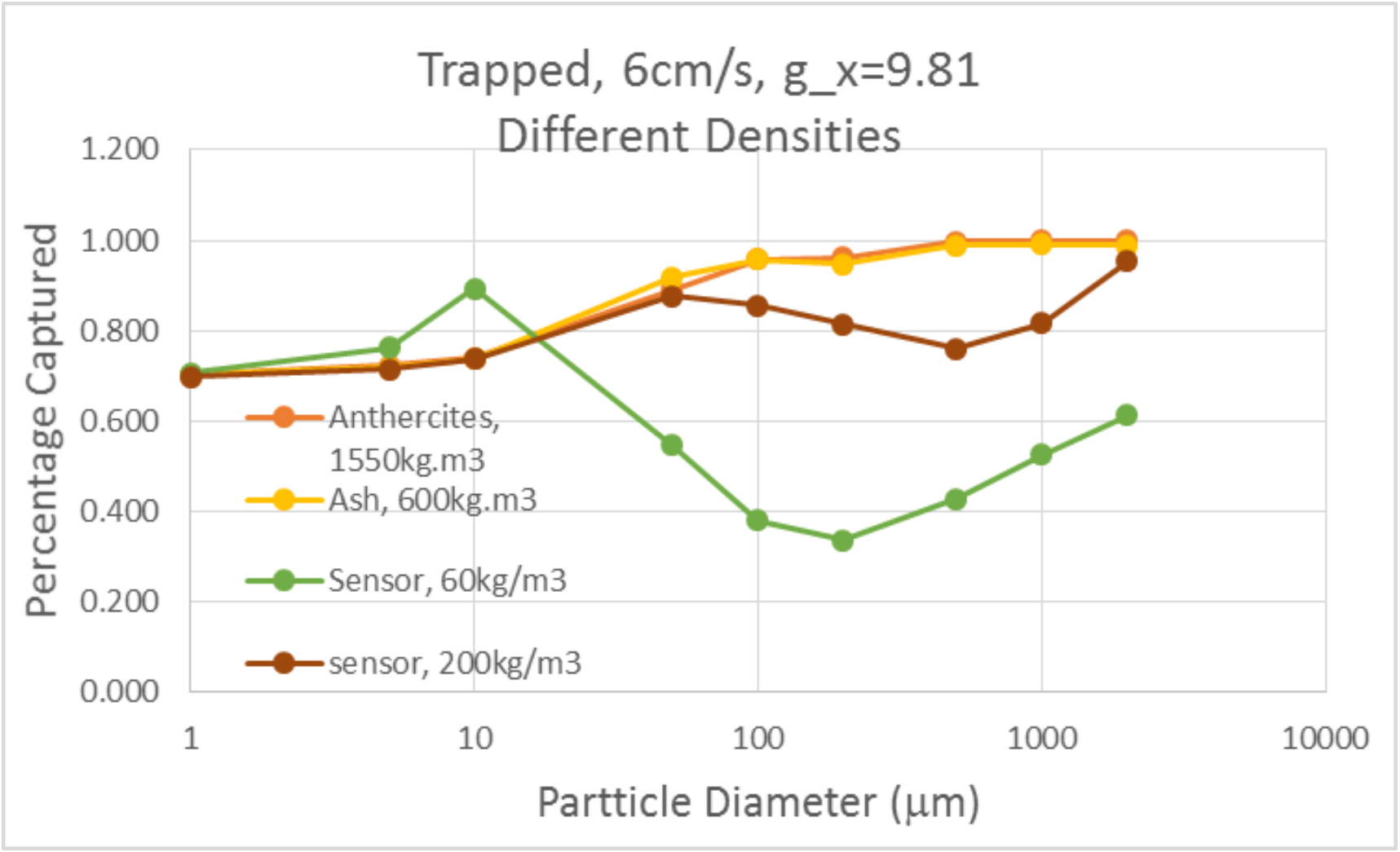

Capture efficiency versus particle diameter. Effect of particle density.

(V_{in} = 6cm/s, g_x=9.81)

Conclusions

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- Computer simulation provided a reasonable tool for providing insight into flows and Proppant transport and deposition in rock fractures.
- Proppant size and density significantly affect the their transport and deposition in fractures.
- Significant portion of the pressure drops in fractures occur in the region with smallest apertures.
- The deposition pattern of proppants are significantly affected by the direction of fracture relative to the gravity.

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Thank You!

Questions?