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

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• 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 Field Operation And Manipulation

  • DEM
    ✓ LIGGGHTS = LAMMPS Improved General Granular and Granular Heat Transfer Simulations

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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

Dynamic Local Mesh Refinement

Results
Idealized Fractures

- 4-way coupling

Unresolved

Resolved ✓
Idealized Fractures

- Drafting
- Kissing
- Tumbling

Fluid Pathlines

Z-Velocity Contours

Graph showing volume flow rate with and without proppant over time.
Idealized Fractures

Pressure Contours

Z-Velocity Contours

Graph: Volume Flow Rate (mL/min) vs. Time (s)

Legend:
- With Proppant
- Without Proppant
Comparison
Fully-Resolved & Unresolved

Velocity Contours

Unresolved
Fully Resolved

Pressure Contours

Unresolved
Fully Resolved
Comparison
Fully-Resolved & Unresolved

<table>
<thead>
<tr>
<th></th>
<th>Unresolved</th>
<th>FullyResolved</th>
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<tbody>
<tr>
<td>Computational Time</td>
<td>1 hour</td>
<td>24 days and 10 hours</td>
</tr>
<tr>
<td>Processors</td>
<td>two Xeon E5-2640 v3 CPU</td>
<td></td>
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Geometry of the large size

Aperture Wall

Aperture Map
Gridding and Geometry of the Fracture
Small Fractures

<table>
<thead>
<tr>
<th>Proppant Diameter (mm)</th>
<th>Injection Rate (1/s)</th>
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</thead>
<tbody>
<tr>
<td>0.2</td>
<td>1000</td>
</tr>
<tr>
<td>0.4</td>
<td>1000</td>
</tr>
<tr>
<td>0.6</td>
<td>1000</td>
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</table>
Clogged Small Fractures

<table>
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<tr>
<th>Proppant Diameter (mm)</th>
<th>Injection Rate (number of proppant/Time) (1/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>10,000</td>
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![Graph showing volume flow rate over time](image-url)
Large Fractures

Proppant Diameter (mm) | 0.4, 0.5, 0.6

Fracture Proppant Coverage (%) vs Time (s)

- dp = 0.40 (mm)
- dp = 0.50 (mm)
- dp = 0.60 (mm)
- Total
Large Fractures

| Proppant Diameter (mm) | 0.5 |

![Fracture Model Image](image)

![Fracture Proppant Coverage Graph](graph)

- dp = 0.50 (mm)
- Total
Large Fractures

Proppant Diameter (mm) | 0.5

Fracture Proppant Coverage (%)

Time (s)
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