Numerical Modeling of Proppant Flow in Fractured Reservoirs

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Introduction

- Increased use of hydraulic fracturing to increase reservoir permeability

- Fractures: Initiated and propagated due to hydraulic loading and pressure by a fluid

- Proppants: Delivered to these fractures to keep them open against the rock pressure

- Hydrodynamics of proppants
  - Proppant distribution
  - Dune formation
  - Fracturing fluid leakoff

- Factors affecting proppant movement
  - Fracture geometry
  - Fracturing fluid properties
  - Proppant properties
Objective of the Study

- Numerical Simulation of proppant movement within the fracture
  - Does not simulate the fracture growth
  - Relevant only after fracture is formed
  - Simulated proppant placement within the fracture

- Evaluate two different techniques for proppant transport simulation
  - Discrete element simulation (DEM)
  - Eulerian granular model

- Sensitivity study to understand parametric dependence
  - Proppant size
  - Fracture fluid viscosity
  - Fracture width

- Simplified three dimensional geometry
  - Rectangular geometry with smooth wall
  - Leakoff at lateral surfaces
Computational Domain and Mesh

- Inlet (Inflow of Water and Proppant Particles)
- Fracture Tip (No-Slip Wall)
- Top and Bottom Walls (No-Slip Wall)
- Side Walls (Water Leak Off)
- Dimensions: 0.05 m, 0.5 m, 1.5 m
Flow Boundary Condition at Walls

- Leakoff rate estimated using a separate simulation with porous wall
- Function of near wall pressure and local velocity
- Simplified formulation: Application for straight and simple geometry used in the study
- Implemented using a
Numerical Scheme

- **General Numerics**
  - Pressure based solver
  - Transient calculations
  - Effect of gravity
  - SST K-ω turbulence model

- **Eulerian granular model**
  - Models multiple separate interactive media
  - Primary phase: slick water; Secondary phase: proppant
  - Drag: Schiller Neumann equation

- **Discrete element simulation technique**
  - In conjunction with dense discrete particle method (DPM)
  - Uniform particle size
  - Contact force laws
    - Normal: Spring dashpot model
    - Tangential: friction-collision law based on Coulomb friction
Physical Properties Used

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proppant (Sand) Diameter</td>
<td>0.001</td>
<td>m</td>
</tr>
<tr>
<td>Proppant (Sand) Density</td>
<td>2719</td>
<td>Kg/m³</td>
</tr>
<tr>
<td>Proppant Flow Rate</td>
<td>2.5</td>
<td>Kg/s</td>
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<tr>
<td>Fluid Density</td>
<td>998</td>
<td>Kg/m³</td>
</tr>
<tr>
<td>Fluid Viscosity</td>
<td>0.001</td>
<td>Kg/m-s</td>
</tr>
<tr>
<td>Fluid inlet velocity</td>
<td>0.5</td>
<td>m/s</td>
</tr>
</tbody>
</table>

- Number of particles for DEM simulations 1200
- Same leakage boundary condition for DEM and Eulerian multiphase flow simulations
Comparison of Two Techniques

➢ DEM: Particle Based Technique
  • Substantial Computational Time and Post Processing Overhead
  • Higher Level of Accuracy

➢ Eulerian Granular Method
  • No explicit Particle Tracking
  • Faster Computational Turnaround
  • Less accurate compared to particle based methods
Comparison of Proppant Particles Propagation Paths

Particle Positions Calculated Using DEM Technique

Volume Fraction of Proppant Calculated Using the Eulerian-Eulerian Technique

Colors Indicate Particle Residence Time

Colors indicate Volume Fraction

Time=0.4 Seconds

Time=0.8 Seconds

Time=1.2 Seconds
Comparison of Proppant Particles Propagation Paths (Cont.)

Particle Positions Calculated Using DEM Technique

Colors Indicate Particle Residence Time

Volume Fraction of Proppant Calculated Using the Eulerian-Eulerian Technique

Colors Indicate Volume Fraction

Time = 1.6 Seconds

Time = 2.0 Seconds
Proppant Movement Simulated using DEM Technique
Proppant Movement Simulated using Eulerian-Eulerian Method
Variation of Filled Fracture Volume With Time

![Graph showing variation of filled fracture volume with time](image-url)
Sensitivity Study for Geometric and Input Parameters

- Used the Eulerian Granular method
- Studied the effects of
  - Proppant diameter
  - Fluid Viscosity
  - Fracture width

<table>
<thead>
<tr>
<th>Simulation Cases</th>
<th>Proppant Diameter</th>
<th>Fluid Viscosity</th>
<th>Fracture Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect of proppant diameter</td>
<td>• 300 µm</td>
<td>1 cP</td>
<td>0.05 m</td>
</tr>
<tr>
<td></td>
<td>• 500 µm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 1000 µm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effect of Fluid Viscosity</td>
<td>1000 µm</td>
<td>• 1 cP</td>
<td>0.05 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 10 cP</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 100 cP</td>
<td></td>
</tr>
<tr>
<td>Effect of fracture width</td>
<td>1000 µm</td>
<td>1 cP</td>
<td>0.01 m, 0.05 m, 1 m</td>
</tr>
</tbody>
</table>
Volume Fraction of Proppant Particle for Different Particle Size

(a) Proppant Diameter: 1000 μm  
(b) Proppant Diameter: 500 μm  
(c) Proppant Diameter: 300 μm
Variation of Filled Fracture Volume With Time for Different Proppant Size
Time Evolution of Proppant Volume Fraction
Volume Fraction of Proppant Particle for Different Fracturing Fluid

(a) Fluid Viscosity: 1 cP
(b) Fluid Viscosity: 10 cP
(c) Fluid Viscosity: 100 cP
Variation of Filled Fracture Volume With Time for Different Fluid
Volume Fraction of Proppant Particle for Different Fracture Width

(a) Fracture Width: 0.05 m
(b) Fracture Width: 0.1 m
(c) Fracture Width: 0.01 m
Variation of Filled Fracture Volume With Time for Different Fracture Width
Summary

- Numerical Simulation of proppant movement within the fracture using Eulerian Granular and DEM techniques
  - Qualitative match between results
  - Spreading rate of the proppant obtained using the Eulerian-Granular method is higher
  - Proppant particles occupy a greater percentage of the volume fraction for the Eulerian-Granular method
  - DEM model seems to provide a more accurate prediction of the solid particle settling behavior

- Parametric Study
  - Proppant size and fracture width significantly affects proppant deposition and settling characteristics
  - Higher viscosity fracturing fluids retards the proppant particles from settling and depositing
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