CFD-DEM MODELING OF THE GRAVEL PACKING PROCESS DURING PETROLEUM HORIZONTAL WELL COMPLETIONS

André L. Martins - PETROBRAS
João V. M. Magalhães - PETROBRAS
Jairo Zago de Souza – ESSS
João A. Aguirre Oliveira Jr – ESSS
Carlos Eduardo Fontes - ESSS
PRESENTATION TOPICS

• Company Overview – Petrobras S.A. / CENPES / TEP

• Problem Description
  – The Gravel Packing Process
  – Why it is necessary?

• Methodology
  – CFD-DEM approach

• Goals

• Conclusion and next steps
Company Overview

- PETROBRAS/CENPES/TEP → Management of Well Engineer Technology
- Responsible by processes involving wells drilling and completion
  - Drilling and completion hydraulics of long horizontal sections and/or complex trajectories
- PETROBRAS has great challenges in drilling horizontal wells, mainly when the reservoir has unconsolidated sandstones
  - Detailed studies has been developed to improve these operations
Problem Description

- During well completion in deep or ultra-deep waters, sand contention is a big problem faced by petroleum engineers;
- To avoid this problem, Petrobras’ engineers usually apply the gravel packing technique in horizontal wells;
- Gravel packing consists of filling the annulus formed between the open reservoir and a screen with particulate material;
- The premature screen out occurs when a beta wave of the gravel packing process forms before filling the entire open hole region.
Problem Description – The Gravel Packing Process

- Operation of filling the annulus formed between the well walls and the screen during the production column introduction;
- The annulus is filled with a proppant, that acts as a “filtering” region to permit only the petroleum flow throughout the production column:

  - The sand-liquid mixture is injected in the platform;
  - The sand deposits in the bottom of the annulus, due gravity effects. This is the alpha wave propagation;
  - When the solids reach the open well end, they start to fill the top of the annulus. This is the beta wave propagation.
Problem Description – Sand Production
Objectives

• Challenges in numerical simulations → Multiphase Flow Modeling
  – Test the CFD-DEM approach to study the gravel packing process
  – Verify the software robustness when working with high solid volume fraction;

• Reproduce numerically the alpha wave of the gravel packing process in different operational conditions.
  – These data can be compared with experimental data provided by PETROBRAS engineers;
Methodology – CFD-DEM approach

- Method that allows working with high particle volume fractions, including deposition and particle-geometry-fluid interaction:
  - The fluid flow is solved through the momentum balance = Navier-Stokes equations:
    \[ \frac{\partial \varepsilon_f \rho U}{\partial t} + \nabla \cdot (\varepsilon_f \rho U U) = -\nabla P + \nabla \cdot (\mu_{eff} (\varepsilon_f \nabla U)) + \rho \varepsilon_f g - S \]
  - The particles trajectories are solved by forces balance over each particle, tracked through the Discrete Element Method:
    \[ F = m \frac{\partial}{\partial t} \left( \frac{\partial r}{\partial t} \right) \quad I \frac{\partial \omega}{\partial t} = \sum M \]

✓ A coupling module promotes the interaction between the phases;
✓ Sources terms are included in the fluid equations, exchanging momentum with the particles via drag forces;
✓ The particle volume fraction is calculated by the average number of particles inside each fluid computational cell.
Methodology - Geometry

- 2D Geometry
- Simplified, but keep the process characteristics
Methodology – Computational Mesh

Hexa Mesh
24000 nodes

1 element of thickness
Methodology – Physical Model

**CFD Side**
- Symmetry condition
- Constant Fluid Properties
  - Specific Mass, Viscosity, etc..
- Turbulent Flow Regime
  - $k$-$\varepsilon$ model;
- Boundary Conditions:
  - Inlet: Prescribed Velocity
  - Outlet: Prescribed Pressure
  - Walls: No slip condition
- ANSYS FLUENT® Software

**DEM Side**
- Periodic Condition
- Constant Particle Shape
  - No particle deformation
- Spherical Particle, with just one particle diameter
- No slip among particle and geometry
- Particle generation rate constant
- DEM Solution EDEM® Software
Methodology – Problem Setup

Particles Factory = 5000 / second

Screen: Restriction to particle flow
Simulated Cases – Different Operational Conditions

Case 1
- Particle diameter: 630 μm
- Density: 2,71
- Fluid flow: 6 BPM

Case 2
- Particle diameter: 630 μm
- Density: 2,71
- Fluid flow: 7 BPM

Case 3
- Particle diameter: 630 μm
- Density: 2,71
- Fluid flow: 8 BPM

Case 4
- Particle diameter: 950 μm
- Density: 1,89
- Fluid flow: 6 BPM
Results – Proppant Volume Fraction and Velocity Profile
Bed Height Evaluation

- The bed height has been evaluated in five different points into the domain.
- Analyze if the bed is stabilized.

The bed height is measured in %, being 100 % the whole well channel.
The experimental tests

- First time that Petrobras carried experimental tests to reproduce de gravel pack displacement in real diameter well
  - Tests carried at HALLIBURTON (Macaé – July/2009)
  - There were three acrylic windows, where it was possible watch the alpha and beta wave displacement
  - The alpha wave height could be measured in several different operational conditions, and the flow was evaluated
## Results – Bed Height

<table>
<thead>
<tr>
<th>Case</th>
<th>Experimental Data</th>
<th>Simulation Data</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>85 %</td>
<td>84,74 %</td>
<td>-0,30 %</td>
</tr>
<tr>
<td>Case 2</td>
<td>84 %</td>
<td>82,5 %</td>
<td>-1,78 %</td>
</tr>
<tr>
<td>Case 3</td>
<td>80 %</td>
<td>79,61 %</td>
<td>-0,49 %</td>
</tr>
<tr>
<td>Case 4</td>
<td>79 %</td>
<td>81,82 %</td>
<td>+3,57 %</td>
</tr>
</tbody>
</table>

Great agreement between simulation and experimental bed height results
Velocity Profile – Flow Characteristics

CFD-DEM approach is able to simulate different granular flow regimes.
Conclusions

• The methodology showed consistent results. The characteristics of process has been reproduced successfully.

• In the simulations, the bed grows up until the fluid flow reaches a critical velocity. At that point, the bed height reaches a plateau and the horizontal particle transport begins;

• The alpha wave has been reproduced successfully. The comparison between simulation and experimental data shows good agreement;

• The approach is almost ready to reproduce the process. This is a promising way to test different operating conditions and obtain the best configuration to the process.
Next Challenges

• The major objective is to simulate a more realistic case, with application in technical operations:
  – Increase the number of particles inside the domain;
  – Work with the real geometry (3D Case);
  – Drastic increase in computational effort – parallel computing.

• Generate results and simulation methods that can be used by Petrobras’ engineers in practical activities:
  – Turning CFD+DEM coupling into a practical design tool for such cases.
THANK YOU!!