Multi-Scale Modeling for Predicting the Productivity of Perforated Completions

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AGENDA

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- OBJECTIVES
- PERFORATION FLOW LABORATORY
- WORKFLOW OVERVIEW
- DAMAGE CHARACTERIZATION
- PRODUCTIVITY ANALYSIS
- CONCLUSIONS
INTRODUCTION

- Perforating (using shaped charges) is widely used to establish hydraulic communication between the formation and wellbore.

- “Clean” perforation tunnels can efficiently transport hydrocarbons. Dynamics of the perforating event inevitably compresses the formation, resulting in “crushed” or “damaged” rock surrounding the tunnel.

- Critical to understand the physical characteristics of the damaged zone
  - Designing/Optimizing perforating jobs
  - Numerical modeling of perforating events

- Challenge – extremely small length scales and arbitrary surface make it impractical for laboratory or traditional modeling methods to quantify the damaged zone.

- Explore the applicability of Digital Rock.
OBJECTIVES

- Application of Digital Rock methodology to characterize and quantify perforation damage in rocks
- Multi-scale simulation approach to accurately predict productivity in perforated rocks
  ✓ Develop fast physics models for cleanup

2 Tariq SPE-20636 (1990)
3 Haggerty et al., SPE-159413 (2013)
4 Detwiler et al., SPE-86538 (2004)
5 Bolchover & Walton, SPE-98220 (2006)
PERFORATION FLOW LABORATORY

The flow laboratory provides the capabilities to:

- Study and qualify the performance of different perforating systems in formation rock at reservoir conditions.
- Study the influence of various factors on well productivity.
- Integrate this knowledge to select the optimal perforating system and clean up strategy for improved productivity.

<table>
<thead>
<tr>
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<th>Section-I</th>
<th>Section-II</th>
<th>Section-II Modified</th>
<th>Section-IV</th>
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<tr>
<td><strong>Target</strong></td>
<td>Concrete</td>
<td>Analog Rock</td>
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<td>15000</td>
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<td>10000</td>
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Free-volume of tunnel
Potential Debris
Planar views
WORKFLOW OVERVIEW

- Section-IV test
- Extract plugs
- CT evaluation
- Pore Space Analysis
- Lattice Boltzmann Simulation
- Permeability Evaluation
- Macro Production Model
DAMAGE CHARACTERIZATION

IMAGE ACQUISITION

- API RP19-B Section IV test performed on Berea sandstone core
- Perforated test section cut into sub-sections
- Cylindrical plugs drilled from multiple sub-sections and pore scale microCT imaging performed (2µm resolution)
- Resulting scans provide detailed pore space geometry for flow simulation analyses
DAMAGE CHARACTERIZATION

PORE SPACE ANALYSIS

- Pore size is calculated with a maximum balls algorithm
- Pore size distributions of the sub-images are compared
DAMAGE CHARACTERIZATION

PERMEABILITY EVALUATION

- Permeability determined from lattice-Boltzmann method simulations
- Permeability increases with distance from tunnel
- 5x permeability change from tunnel surface to native rock
DAMAGE CHARACTERIZATION

WHOLE FIELD VISUALIZATION

Native: Porosity=12.5%, K0 = 139 mD

Damaged: Porosity=11.0%, K0 = 61 mD
PRODUCTIVITY ANALYSIS
PERFORATION TUNNEL MODELING

- Simulations performed using Lattice-Boltzmann method with porous media model
- Native rock permeability 200 mD
- Damage zone permeability 50 mD
PRODUCTIVITY ANALYSIS

PRODUCTIVITY RATIO RESULTS

- Various scenarios and effects easily studied

<table>
<thead>
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<th>Productivity Ratio</th>
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<td>1</td>
</tr>
<tr>
<td>1</td>
<td>2.71 l/min</td>
<td>0.76</td>
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<td>4</td>
<td>5.29 l/min</td>
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**PRODUCTIVITY ANALYSIS**

**FLOW VISUALIZATION**

**Case 4: Damage & Slug**

- Nearly all of the pressure drop occurs from the inlet to the toe
- Flow concentrates at the toe of the tunnel, causing highest pressure gradient.

![Velocity](image)

![Pressure](image)

![Pressure Gradient Mag](image)

![Streamlines](image)
PRODUCTIVITY ANALYSIS

FLOW VARIATIONS

- Presence of damage zone moves the tunnel flow entry downstream
- Presence of slug increases the effect
PRODUCTIVITY ANALYSIS
SLUG EFFECT

- Introducing a slug to the toe of the tunnel shifts the flow entry downstream.

![Diagram showing flow fraction with and without slug](image)

**Flow fraction**
- With slug
- Without slug

MENAPS 16-06

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CONCLUSIONS

- Multi-scale approach to modeling perforation tunnel productivity is demonstrated
- Pore scale simulations are important to quantify the damage zone permeability
- Resulting permeability characterization allows detailed perforation productivity analysis

Future Work
- Couple results to fast-physics models for DUB (See MENAPS 16-25)
- Realistic reservoir domain
- Upscale from lab-to-field scale flow modeling
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QUESTIONS?
THANK YOU!