The impact of foam fracturing fluids on water consumption

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Presented to: International Petroleum Environmental Conference
November 8-10, 2016
New Orleans, Louisiana
Motivation and Objective

• Motivation
  • Reduce water consumption
  • Optimize Well Productivity
    • Identify opportunities to improve well performance using foams

• Objectives
  • Understand foam properties
  • Evaluate foam performance for proppant transport

• This Presentation
  • Focus on water savings perspective
Water in Hydraulic Fracturing

- Disposal issues
  - Chemicals, salinity, NORM
  - Earthquakes
  - Transportation

Currently: 3MM to 8MM gal/well and increasing...

Fracfocus

Average Hydraulic Fracturing Fluid Composition for US Shale Plays

3X Water consumption

FracWater Used / Well

Average frac volume (bbl water/well)

FracKnowledge Frac Database.

3MM to 8MM gal/well and increasing...
Foam Fluids Impact on Water Consumption

- **Water Replacement**
  - “80-quality” foam is 80% N2 by volume (water volume reduction)

- **Proppant Placement Effects**

- **Leak-off Effects**

- **For Nitrogen foams, transport and storage requirements are also reduced by Volume Effects**

Foam Fracturing Fluids reduce water consumption through multiple synergistic effects
Foam Fluids Impact on Water Consumption

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Proppant Consumption Trends

- Proppant lbs/ft trends:
  - Pioneer Published Frac Design:
    - 2014: 1000 lbs/ft
    - 2015: 1400 lbs/ft
    - 2016: 1700 lbs/ft
  - Chesapeake “Prop-a-geddon”
    - 3000 lbs/ft

Increasing Proppant Consumption/ft is indicative of the importance of proppant placement

“Percentage breakdown of cost shares for U.S. onshore oil and natural gas drilling and completion”. Source: IHS Oil and Gas Upstream Cost Study commissioned by EIA
Simulation-based Study

M-frac simulation Presented at AAPG 2014

Slickwater delivers proppant to a smaller volume than foam, despite longer fracture.
New Laboratory Apparatus

- 2,400psi (160 bar) operating pressure
- Foam Rheology and Stability Measurements
- Proppant Transport Measurement
Experimental Approach
Proppant Transport Mechanism for Water

Growth and propagation of sand bed

Kern et al., 1959

Water – Proppant
Proppant Transport Water vs. N\textsubscript{2} foam

- Images from Air Liquide Laboratory

Water – Proppant

80% Foam – Proppant

Water: Mainly translational transport

Foam: Mainly buoyant transport
Proppant Placement - Summary

- We have observed that industry is using higher Proppant lbs/ft, despite lower oil price, which highlights the importance of proppant placement.

- Foam fracturing fluids provide improved proppant transport
  - Supported by simulation results
  - Direct experimental measurement starting to come on-line
  - Will be coupled with computational fluid dynamics to provide needed understanding

- **We propose** that foam fracturing fluids will provide improved productivity without massive proppant injection/massive fluid volumes, due to improved proppant placement
  - Tuning of the foam rheology will be required to optimize fracture dimensions
Foam Fluids Impact on Water Consumption

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Leak-off effects

• Leak-off fluid losses are typically >50% for slickwater

• Foams reduce leakoff, not only through reduced water injection volume, but also through modification of leak-off physics

• Leak-off physics effects follow from foam quality and structure
  • Can be explained in terms of Surface Area effect on Osmotic Pressure (due to Princen)
  • Osmotic Pressure of the foam is a driving force to retain water in the fracture
Foam Quality and Structure

Low quality foam

High quality foam

120° angle (Plateau structure)

Energized Fluid

<table>
<thead>
<tr>
<th>Dilute</th>
<th>Semi-Dilute</th>
<th>Intermediate</th>
<th>Condensate</th>
</tr>
</thead>
</table>

Foam

Mist

Gas Volume Fraction ($\phi_g$)

0 0.1 0.2 0.4 0.64-0.74 0.94-0.99 1

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### Basis of Leakoff Effect: Osmotic Pressure (Princen)

<table>
<thead>
<tr>
<th>Energized Fluid</th>
<th>Foam</th>
<th>Mist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dilute</td>
<td>Wet Limit</td>
<td>Dry Limit</td>
</tr>
<tr>
<td>Semi-Dilute</td>
<td>Increasing Surface Energy and Osmotic Pressure</td>
<td></td>
</tr>
<tr>
<td>Intermediate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condensate</td>
<td></td>
<td>0.94-0.99</td>
</tr>
</tbody>
</table>

*Gas Volume Fraction ($\phi_g$)*

- Beyond the wet limit, further loss of liquid requires a surface area increase
  - Spheres $\rightarrow$ Polyhedra

Dry Foams resist fluid loss

\[
E = \gamma \sum_{i=1}^{n} S_i = \gamma S_{tot}
\]
Experimental Observation of Leakoff Effect (Ribeiro & Sharma)

- Leak-off Rate
  (Carter, 1957; Ribeiro & Sharma, 2012)

\[
\sum_{j=1}^{WP} 2C_{w_j} \frac{\rho_j}{\sqrt{t - \tau}}
\]

- Leak-off Coefficient decreases with foam quality (x1/2 to x1/5)

Leakoff Rate is Reduced More than Expected Based on Volume Replacement Alone
Leak-off Effects - Summary

- Foam Osmotic Pressure is a driving force to retain liquid in the foam and reduce leak-off more than expected by simple volume replacement.
Foam Fluids Impact on Water Consumption

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Volume Effects

- Densities of CO$_2$ and N$_2$ are lower than H$_2$O under downhole conditions, but similar to water under surface transport and storage conditions.
- Mass of N$_2$ to replace a given volume of water is much less than mass of water.
- This results in lower truck traffic requirements and site storage volumes.
Volume Effects

Equivalent Surface Volumes of CO\textsubscript{2} and especially N\textsubscript{2} convert to larger volumes downhole.
Total Fluid Volume Required for Foams vs. Water (example)

Calculated for hypothetical Utica example (75 quality foam), and presented at AAPG 2014. Estimates do not account for differences in leakoff effects, solubility or cool-down requirements.

<table>
<thead>
<tr>
<th>Consumption</th>
<th>Slickwater</th>
<th>CO₂ foam</th>
<th>N₂ foam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proppant (lbs)</td>
<td>3.0E05</td>
<td>3.0E05</td>
<td>3.0E05</td>
</tr>
<tr>
<td>Total Water (gallons)</td>
<td>156,300</td>
<td>47,545</td>
<td>47,545</td>
</tr>
<tr>
<td>CO₂ or N₂ (US tons)</td>
<td>NA</td>
<td>340</td>
<td>149</td>
</tr>
<tr>
<td>CO₂ or N₂ Surface Volume (gallons)</td>
<td>NA</td>
<td>80,300</td>
<td>44,200</td>
</tr>
<tr>
<td>Total Volume Fluid (gallons)</td>
<td>156,300</td>
<td>127,845</td>
<td>91,745</td>
</tr>
<tr>
<td>Surface pressure (psi)</td>
<td>3200</td>
<td>3800</td>
<td>4600</td>
</tr>
</tbody>
</table>

Nitrogen requires the least storage and transport, slickwater the most. Surface pressure requirements are the reverse.
Summary

• Foam Fracturing Fluids reduce water consumption

• Reduction in consumption is augmented by synergistic effects
  • Proppant Placement
  • Leak-off Reduction (Osmotic pressure effect)

• Environmental impact is further reduced by Volume Effects
Acknowledgements

The authors acknowledge the support of this project by the Air Liquide business units and permission from Air Liquide management to publish this work.

THANK YOU FOR YOUR ATTENTION
Impact of water on productivity

- **Water sensitivity**
  - Fines migration and clay swelling

- **Water block**
  - Low perm rock traps wetting phase
  - High capillary pressure to overcome for oil and gas displacing water
  - Low relative permeability

- **Cleanup and proppant conductivity**
  - Water based gel hard to cleanup
  - Gas bubble helps flow back

- **Water availability and disposal cost**
  - EUR, economics, environment

Dawson et al. 2013.

Mohan et al, 1993