New Technologies to Expand Foamer Applications

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1. Introduction
   • Benefit of foamer application in gas wells
   • Current foamer technology and gap

2. Offshore foamer applications
   • Challenges in offshore applications
   • Successful condensate foamer application

3. New crude oil foamer to increase oil and gas production
   • Product development and lab evaluation
   • Successful oil foamer application

4. Conclusions
Flow Regime Change of a Well

Flow - The Life of a Gas Well
The consequences of depletion in a gas well

Gas Production Rate

Time

Annular Flow
Benefits of Foamer Applications

• Without removing liquid, the production decreases rapidly and ceases prematurely.

• Deliquification technologies enhance gas production and $$$.

• Foamers are simple and economic technologies for low producing wells.

• No downhole equipment is required.

• Can be used with gas lift or plunger lift to enhance production further.
How Do Foamers Work?

• Foamer reduces critical velocity ($V_t$) that is needed to lift the fluid up the production tubing by reducing the density and surface tension of liquid.

$$V_t = 1.593 \left[ \sigma^{1/4} (\rho_l - \rho_g)^{1/4} \right] / (\rho_g)^{1/2}$$
Gap in Current Foamer Technology

- Water based foamers are cost effective deliquification technology for on-land wells.
- Foamers have not been applied offshore often.
- Traditional foamers are not cost effective to treat crude oils.
Offshore Thailand gas wells experience fluid loading issues

- Reaches critical rate after 2 – 3 years
- Current solution – wells flow intermittently
- No artificial lift currently in place
- Wells shut in due to fluid loading
Challenges in Offshore Applications

- Offshore wells have a surface safety valve and subsurface safety valve
- Capillary can not be hung from the top of a standard wellhead like typical land wells installations
1. Modified WRSCSSV
   • Provides chemical flow path around flapper valve
   • SCSSV still fully functional
   • No workover required

2. Wellhead Adapter
   • Capillary hung below all tree valves
   • Still have access to BPT
   • Maintain fully functionality of wellhead
Installation Equipment
InjectSafe® Safety Valve
Offshore Foamer Application in Thailand

• Performed trials on 3 wells in Gulf of Thailand in January 2009
• Ran capillary to set depth and pumped foamer while flowing the well for several days
• Results were promising and led eventually to a permanent installation
• Example presented is from Funan Field, Well #9
  o Fluids produced > 80% condensate
Successful Condensate Foamer Application

Condensate foamer application increased gas production by unloading well fluids.
Requirements for Oil Foamer Development

✓ Identify appropriate chemistry to foam crude oil
  • Formulated for different application methods
  • Ensure chemical stability in well bore environment
  • Pose no impact on integrity of asset
  • Perform in wide range of oils
## Oil Foamers for Different Applications

<table>
<thead>
<tr>
<th></th>
<th>Oil foamer A</th>
<th>Oil foamer B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas lift application?</td>
<td>Yes *</td>
<td>No</td>
</tr>
<tr>
<td>Capillary approved up to</td>
<td>300 °F</td>
<td>200 °F</td>
</tr>
</tbody>
</table>

- Oil foamer A passed gunking test.
Impact on Asset Integrity Was Evaluated

- Verified material compatibility using common materials used in assets
  - Metals – Not corrosive to aluminum, copper, mild steel, SS304, SS316
  - Plastics – Compatible with Teflon, HD polyethylene, linear Polyethylene, HD polypropylene
  - Elastomers – Compatible with Viton, Hypalon, EPDM rubber
Candidate Evaluation Process

- Dynamic foam column tests simulate both batch and continuous treatment
- Tested at system temperature and production rate by controlling flow rate
Foamer Reduces Density Significantly

- Foamers expand the volume of fluids significantly, i.e. the reduction of density of fluids.
- Temperature and flow rate were set to simulate the well conditions.
## Oil Foamers Evaluated in Different Samples

<table>
<thead>
<tr>
<th></th>
<th>Well #1</th>
<th>Well #2</th>
<th>Well #3</th>
<th>Well #4</th>
<th>Well #5</th>
<th>Well #6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil production, BOPD</td>
<td>1630</td>
<td>600</td>
<td>850</td>
<td>50</td>
<td>340</td>
<td>315</td>
</tr>
<tr>
<td>Water production, BWPD</td>
<td>20</td>
<td>30</td>
<td>90</td>
<td>50</td>
<td>185</td>
<td>270</td>
</tr>
<tr>
<td>API gravity</td>
<td>30</td>
<td>33.5</td>
<td>32</td>
<td>40</td>
<td>34.5</td>
<td>36.3</td>
</tr>
<tr>
<td>Bottom hole temperature, °F</td>
<td>137</td>
<td>192</td>
<td>133</td>
<td>300</td>
<td>183</td>
<td>168</td>
</tr>
<tr>
<td>Gas lift application?</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Oil foamer tested</td>
<td>Oil foamer B</td>
<td>Oil foamer A</td>
<td>Oil foamer A</td>
<td>Oil foamer A</td>
<td>Oil foamer A</td>
<td>Oil foamer A</td>
</tr>
<tr>
<td>Recommended foamer dosage, ppm</td>
<td>5,000</td>
<td>2,000</td>
<td>1,000</td>
<td>1,500</td>
<td>2,500</td>
<td>500</td>
</tr>
<tr>
<td>Oil foamer effective?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

- Oil foamers were evaluated in different samples.
- The recommended dosage is based on lab tests. The dosage would be optimized during the field application.
# Product Development Summary

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Method</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novel oil soluble chemistry</td>
<td>Patent pending</td>
<td>✓</td>
</tr>
<tr>
<td>Foamer performance evaluation</td>
<td>Dynamic foam column tests</td>
<td>✓</td>
</tr>
<tr>
<td>Chemical stability</td>
<td>Capillary test and gunking test</td>
<td>✓</td>
</tr>
<tr>
<td>Asset integrity</td>
<td>Material compatibility tests</td>
<td>✓</td>
</tr>
</tbody>
</table>
Successful Oil Foamer Field Trial

EOG Resources South Texas Oil Well
Requirements for Successful Applications

- ✔ Determine potential success as a foamer application
  - Well information
  - FOAM modeling
  - Performance evaluation
- ✔ Defoamer controls foam issue effectively
**Well Information**

<table>
<thead>
<tr>
<th>Days of production$^{(1)}$</th>
<th>7 days on/7 days off</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well Depth, feet$^{(2)}$</td>
<td>13,000</td>
</tr>
<tr>
<td>Gas production, Mcf/D</td>
<td>250</td>
</tr>
<tr>
<td>Oil production, BOPD</td>
<td>40</td>
</tr>
<tr>
<td>Water production, BWPD</td>
<td>40</td>
</tr>
<tr>
<td>API gravity, °</td>
<td>40</td>
</tr>
<tr>
<td>Bottom hole temperature, °F</td>
<td>300</td>
</tr>
</tbody>
</table>

$^{(1)}$A water based foamer was injected continuously.

$^{(2)}$The capillary is installed closed to perforation and good mixing of produced fluids and foamer is expected.
Foam Modeling

- Baker Hughes’ proprietary software
- Calculate gas velocity (V) and gas critical velocity ($V_t$)

Above 1 means the well is unloaded
Below 1 means the well is loaded

$V_t << V$ Well flows

$V_t >> V$ Well loaded up
Foamer Evaluation to Determine Dosage

- Flow rate and temperature for testing simulate the well condition.
- The recommended dosage is 1,500 ppm. The dosage needs to be optimized during field application.
Defoamer Evaluation for Foam Control

- Defoamer X was most effective product.
EOG Field Trial-Production Data

- Oil foamer dosage was optimized to 750 ppm
- Defoamer dosage was optimized to 750 ppm
- Rag tests confirmed that defoamer controlled foam issue

Oil Foamer injected 7/26/10
EOG Field Trial-Summary

<table>
<thead>
<tr>
<th></th>
<th>Before oil foamer(^{(1)})</th>
<th>After oil foamer</th>
<th>No foamer at all(^{(2)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days of production</td>
<td>7</td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>Gas production, Mscf/D</td>
<td>122</td>
<td>400</td>
<td>192</td>
</tr>
<tr>
<td>Oil production, BOPD</td>
<td>13</td>
<td>100</td>
<td>24</td>
</tr>
</tbody>
</table>

\(^{(1)}\) A water based foamer was injected continuously.

\(^{(2)}\) The data was collected after cutting off oil foamer A.
Conclusions

1. Foamer technology has extended to treat condensates and crude oils.
2. InjectSafe® solved the challenge in foamer offshore applications.
3. Successful field trial proves that the new crude oil foamer enhances both oil and gas production.
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- Thailand field trial: Mark Embrey
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