Reverse Osmosis (RO) Membrane Compatible Foamers: a Sustainable Deliquification Solution

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Outline

• Background

• Coal Bed Methane (CBM) production, produced water management & deliquification techniques

• Development of Reverse Osmosis (RO) membrane compatible foamers as sustainable deliquification solution

• Field performance of RO foamers

• Summary
Background - CBM Production

- Large drilling campaigns for CBM wells to supply new liquefied natural gas (LNG) plants
- The demand for LNG in AP continues by 2015 is expected to consume 80% of the global trade
- The volume of the produced water from CBM production is significant, so sustainable management strategy such as RO filtration and beneficial reuse of the purified water is very crucial
Background - CBM Production in Queensland, Australia

Source: Australia in Focus, April 4th, 2011
Background - CBM Production

- CBM is produced by drilling into a coal seam where typically naturally occurring water is also present.
- Water is produced to reduce pressure so that natural gas (mainly methane) can desorb from the coal surface and be produced.
- Efficient and controlled removal of water is critical to maximize the CBM production.
Background – Produced Water Management

- The volume of produced water from CBM is **significant** and thus, **re-use is an important environmental consideration**, especially for areas with water restrictions such as Australia.

- Government authorities require the produced water be treated to a level to enable beneficial reuse in various applications such as:
  - **Aquaculture**
  - **Irrigation**
  - **Mining operations and power stations**
  - **Etc.**

- The produced water is often **very saline** and can also **contain particulates**, so some form of **treatment** is required before reuse.
Background – Produced Water Management

Evaporation ponds

- Historically used as standard
- Expensive
- Environmental concerns
  - Wildlife
  - Leaks and spills
  - Flooding in wet season
- Environmental authorities shifted towards the use of more environmentally friendly Reverse Osmosis (RO) plants
- Phasing out evaporation ponds as the primary means of disposal

1.5-3 Million L /day
Background – Produced Water Management

- 12 Million L/day capacity RO plant
- One of the beneficial uses is irrigation of a 480 hectare (1188 acres) plantation of Pongamia trees has been selected as the optimum use
- This RO plant received award from Australian Petroleum Production & Exploration Association Ltd (APPEA)

Ref. Overview of Origin’s CSG position, June 30, 2009
RO Technology

- The materials used in the membranes are very sensitive to chemicals in the water stream.

- Chemical fouling make conventional foamers not suitable for this application.
Background - CBM Deliquification Techniques

Pros: can handle some solids if rotated slowly

Cons:
• volumetric output affected by presence of solids
• required speed & power affected by fluid viscosity and lift demand
• expensive to install, operate, and maintain, particularly in CBM applications where frequent bore cleaning is required
• depth limited
• safety concern - rotating parts at surface

Progressive Cavity Pumps (PCP)
Background - CBM Deliquification Techniques

**Pros:**
- cost-effective to apply
- foamer/corrosion inhibitor/scale inhibitor combination

**Cons:**
- chemical residue in the produced water
- surface upset (separator, RO unit etc.)
- foam stability, thus performance, affected by solids
Development of RO Compatible Foamers

• RO membrane compatibility test

• Dynamic foaming test

• Corrosion test
Development of RO Compatible Foamers – RO Membrane Compatibility

The **industry standard test protocol** was utilized

**RO Membrane:** Filmtec BW30 membrane

**Membrane QC specifications:**
- Feed Composition: NaCl
- Feed Concentration: 2000 ppm
- Feed Temperature: 25 °C
- Feed Pressure: 220 psi
- Permeate Flow: 45 Liter/M²/Hour
- Minimum Rejection: 99.5%
Two Key Parameters

Salt Rejection = (Feed TDS – Product TDS) / Feed TDS

**Flux**: the rate of permeate transported per unit of membrane areas (gallon per square foot per day)
Development of RO Compatible Foamers – RO Membrane Compatibility Cont.

- **Circulation test:** flux and salt rejection monitored at 2, 6 and 24 hours
- **14 days soak test:** flux and salt rejection measured after soaking
- **“Standard”:** The base line salt rejection and flux was determined for each membrane sample utilizing the standard brine solution

The chemicals must not negatively impact the membrane performance!!!
Flux Performance of Best-in-class Non-RO Amphotheric Foamer 1
Flux Performance of Best-in-class Non-RO Anionic Foamer 2
Flux Performance of RO Foamer EC7022RO
Development of RO Compatible Foamers Dynamic Foaming Performance Test (DFP)

- RO membrane compatibility test
- Dynamic foaming test
- Corrosion test
Development of RO Compatible Foamers – DFP Test Apparatus

Nalco Deliquification Unloading Rig – Modified ASTM 892
Development of RO Compatible Foamers – DFP Test Results

- RO Foamer Brine 1
- RO Foamer Brine 2
- Best in Class Non-RO foamer brine 1
- Best in Class Non-RO foamer brine 2
Development of RO Compatible Foamers
Dynamic Foaming Performance Test (DFP)

- RO membrane compatibility test
- Dynamic foaming test
- Corrosion test
## Development of RO Compatible Foamers – Corrosion Test

<table>
<thead>
<tr>
<th>Metal</th>
<th>Chemical</th>
<th>MPY</th>
<th>Pitting at 10X</th>
<th>7 days MCT result**</th>
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</thead>
<tbody>
<tr>
<td>SS2205</td>
<td>Neat EC7022RO</td>
<td>Not measurable</td>
<td>None</td>
<td>Pass</td>
</tr>
<tr>
<td>C1018</td>
<td>Neat EC7022RO</td>
<td>1.14</td>
<td>Uniform</td>
<td>Pass</td>
</tr>
<tr>
<td>C1018</td>
<td>Synthetic brine*</td>
<td>5.21</td>
<td>Severe</td>
<td>Fail</td>
</tr>
<tr>
<td>C1018</td>
<td>5000 ppm EC7022RO in synthetic brine*</td>
<td>2.18</td>
<td>Uniform</td>
<td>Pass</td>
</tr>
</tbody>
</table>

NES Criteria: Metal corrosion rates not to exceed 3.0 MPY
Metals should have no visual pitting at 10X

Test Temperature = 130°F
* EC7022RO Concentration = 5000 ppm
** Synthetic Brine Composition: NaCl = 5.3 g/liter and CaCl₂ = 0.44 g/liter
Take the Technology to the Field

NALCO LIFT PROCESS

1 Analyze Field
- Historical production data; well downtime history;
- Well shut-in and flowing parameters

2 Model Wells
- Evaluate the severity of the liquid loading

3 Rank Wells
- Determine and rank by the probability of success and by impact in increased gas production

4 Recommend Specialized Products
- BHP, completion, % hydrocarbon, pour point etc.
- Recommend most suitable application method

5 Execute
- Systematic approach, optimization, monitoring etc.
Field Performance of RO Foamer EC7022RO

• Its effectiveness was proven in the field with RO units at customer site 1

• Many CBM wells showed >100% production gains without upset in RO unit

• Pending field trial at customer site 2
Foamer-aided Lift Wells

<table>
<thead>
<tr>
<th>WELL</th>
<th>Water BBL's Per/day</th>
<th>Surfactant Gal per/day</th>
<th>Pre installation Rate (Mscf/d)</th>
<th>Post installation 30 Days (Mscf/d)</th>
<th>60 Days (Mscf/d)</th>
<th>90 Days (Mscf/d)</th>
<th>% Increase After 90 Days</th>
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<tbody>
<tr>
<td>Well 1</td>
<td>70</td>
<td>1.17</td>
<td>120</td>
<td>199</td>
<td>166</td>
<td>214</td>
<td>78%</td>
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<td>Well 2</td>
<td>45</td>
<td>0.75</td>
<td>98</td>
<td>244</td>
<td>221</td>
<td>230</td>
<td>135%</td>
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<tr>
<td>Well 3</td>
<td>62</td>
<td>1.03</td>
<td>104</td>
<td>167</td>
<td>213</td>
<td>208</td>
<td>100%</td>
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<tr>
<td>Well 4</td>
<td>84</td>
<td>1.40</td>
<td>139</td>
<td>218</td>
<td>233</td>
<td>208</td>
<td>50%</td>
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<tr>
<td>Well 5</td>
<td>86</td>
<td>1.43</td>
<td>121</td>
<td>178</td>
<td>176</td>
<td>167</td>
<td>38%</td>
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<tr>
<td>Well 6</td>
<td>33</td>
<td>0.55</td>
<td>90</td>
<td>214</td>
<td>208</td>
<td>192</td>
<td>113%</td>
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</table>

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<tr>
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<th>60 Days (Mscf/d)</th>
<th>90 Days (Mscf/d)</th>
<th>% Increase After 90 Days</th>
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<tr>
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<td>109</td>
<td>1.82</td>
<td>150</td>
<td>236</td>
<td>240</td>
<td>240</td>
<td>60%</td>
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<tr>
<td>Well 43</td>
<td>43</td>
<td>0.72</td>
<td>10</td>
<td>96</td>
<td>141</td>
<td>163</td>
<td>1530%</td>
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<tr>
<td>Well 44</td>
<td>53</td>
<td>0.88</td>
<td>110</td>
<td>210</td>
<td>200</td>
<td>198</td>
<td>80%</td>
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<tr>
<td>Well 45</td>
<td>71</td>
<td>1.18</td>
<td>10</td>
<td>200</td>
<td>203</td>
<td>204</td>
<td>1940%</td>
</tr>
<tr>
<td>Well 46</td>
<td>44</td>
<td>0.73</td>
<td>10</td>
<td>165</td>
<td>165</td>
<td>170</td>
<td>1600%</td>
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<tr>
<td>Well 47</td>
<td>79</td>
<td>1.32</td>
<td>10</td>
<td>190</td>
<td>220</td>
<td>300</td>
<td>2900%</td>
</tr>
</tbody>
</table>
Summary

• The volume of the produced water from CBM production is significant, so sustainable management strategy such as RO filtration and beneficial reuse of the purified water is very crucial.
• The challenge with using a chemical solution is compatibility with the RO membrane in the produced water treating system.
• Nalco has recently developed technology-breakthrough foamer EC7022RO, which is RO membrane compatible and suitable for system with RO plant.
• EC7022RO has been proven in the field to offer a cost effective alternative to mechanical artificial lift and provide sustainable deliquification solution to the CBM wells with RO water treatment unit.
• Nalco’s 5-step Lift Process has been the foundation for many recommendations and successful field applications.
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