Is Gas-lift in its Current State Ready to Support Deep Gulf of Mexico Production Planned for 2015 and Beyond?

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Shell E&P Wells Artificial Lift
## 2015 and Beyond Requirements

### Well conditions

<p>| | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td><strong>Water Depth</strong></td>
<td>4000 – 10000 ft (1219 – 3048 meters)</td>
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<tr>
<td><strong>SBHP</strong></td>
<td>15000 – 24000 PSI (1034 – 1655 bar)</td>
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<tr>
<td><strong>SBHT</strong></td>
<td>250 – 375 °F (121 – 191 °C)</td>
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<tr>
<td><strong>Injection Gas Pressure at FCD</strong></td>
<td>5000 – 9000 psi (345 – 621 bar)</td>
</tr>
<tr>
<td><strong>Injection Gas Rates</strong></td>
<td>10 – 15 MMscfd (283 – 424 MSm³/d)</td>
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What does Gas-lift Compete Against?

- Caisson ESP systems
- Subsea multiphase boost pumps
- Subsea horizontal ESPs
- Subsea separator with liquid boost pumps
- Subsea water separation and reinjection
BC-10 Caisson ESP System

6 Wells

Manifold

Oil Pipeline

2 Caisson ESP Boost Systems

Gas Pipeline (optional)
### Tordis SSBI
Produced Water Separation and Injection and Multiphase Boosting

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
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<tbody>
<tr>
<td><strong>Client</strong></td>
<td>StatoilHydro</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>Norway</td>
</tr>
<tr>
<td><strong>Water depth</strong></td>
<td>650’ (220 m)</td>
</tr>
<tr>
<td><strong>Step-Out</strong></td>
<td>6.9 mi (12 km)</td>
</tr>
<tr>
<td><strong>Design Pressure</strong></td>
<td>3,000 psi</td>
</tr>
<tr>
<td><strong>Liquid Capacity</strong></td>
<td>100,000 bwpd and 50,000 bopd</td>
</tr>
<tr>
<td><strong>MultiPhase Pump</strong></td>
<td>Helico-Axial to 68% GVF 2.3MW 450 psid (38 bar.d)</td>
</tr>
<tr>
<td><strong>Water Injection Pump</strong></td>
<td>Single Phase 2.3MW 1100 psid (75 bar.d)</td>
</tr>
<tr>
<td><strong>Installation/Start</strong></td>
<td>August 2007 / November 2007</td>
</tr>
<tr>
<td><strong>Scope of Work</strong></td>
<td>Subsea Separator Station, Pump, control</td>
</tr>
</tbody>
</table>

- **First sand management system**
- **First density profile (sand, water, emulsion, oil and foam)**
- **First semi-compact separator (centrifugal gas separation and by-pass)**
- **Semi-compact separator 2.0m od x 12m t/t**
### Total Pazflor Angola

**Gas-Liquid Separation and Liquid Boosting**

- **Client:** Total
- **Location:** Angola
- **Water depth:** 2700’ (740 m)
- **Step-Out:** 2.5 mi (4.5 km)
- **Design Pressure:** 2,750 psi
- **Process Capacity:** 110,000 bopd and 35 MMSf/d (1.0 MMSm³/d)
- **Gas Tolerant Pump:** Hybrid to 18% GVF
- **Gas:** Free flows through 2 x 6” flowlines
- **Project Award:** December 2007
- **Scope of Work:** Subsea Separator Station, Pump, control

- First Gas-Liquid Gravity Separation system
- First Hybrid pump system with subsea barrier fluid control
- Separator 3.5m od x 9.0m t/ t
Cascade / Chinook
Horizontal ESPs in Cartridge

Client: Petrobras Americas
Location: GoM Lower Tertiary, Walker Ridge
Water depth: 8800’ (2700 m)
Step-Out: 14 mi (25.0 km)
Design Pressure: 12,900 psia
HV Penetrator
Process Capacity: 2 Cartridges per Station
40,000 bpd per Station
Gas Tolerant ESP: ESP to 15% GVF
22,000 bopd pump systems
Series Pumps 2 x 0.6 MW
3200 psi duty - 1600 psid (110 bar.d) each
Project Award: August 2007
Solution: ESP Liquid Boosting
Scope of Work: Subsea Pump System, PDU/UTH, manifolding, Controls, Flow Manager

- First Series ESP system
- First Series ESP with first ESP designed to handle gas (to 30%)
- First Single cable connecting two ESPs (electrically parallel)
- First Horizontal ESP packaging
- Cartridge 9’ x 14’ x 91’ long x 205,000 lbs

Courtesy of FMC
Petrobras Congro & Corvina
Gas-Liquid Separation and Liquid Boosting

Client : Petrobras
Location : Brazil
Water depth : 650’ (197 m) and 900’ (280m)
Step-Out : 7 and 5 mi (11 and 8 km)
Design Pressure : 3,000 psi
Process Capacity : 20,000 bopd ea. and 30 MMSf/d (850 MSm3/d)
Gas Tolerant Pump: ESP to 10% GVF
1 x 20,000 blpd pump
0.4MW 300 psid (20 bar.d).
Gas: Free flows
Project Award : May 2011
Scope of Work : Subsea Separator Station, Manifold, Pump, control

» Gas-Liquid Gravity Separation system on torpedo pile
» Separator 1.0m od x 35m t/t VASPS
» Subsea pig-launcher and diverter valve for pigging gas or liquid lines

Courtesy of FMC
Petrobras Marlim Brazil
Produced Water Separation and Injection Pilot

Client: Petrobras
Location: Brazil
Water depth: 2950' (900 m)
Step-Out: 3 mi (5.0 km) from P-37
Design Pressure: 5,000 psi
Process Capacity: Pipe Separator
22,000 bpd @ ~67% w-c
3500 m3/d, 22 API

Produced Water: Multistage Centrifugal Injection Pump: 20,000 bwpd pump systems
1.9 MW Motor, DP 3500 psi (245 bar)

Hydrocarbons: Free flows through 6” flowline
Project Award: December 2009
Scope of Work: Subsea Separator Station, Produced Water Processing, Pump, and Controls

» First Application of Pipe Separator
» First Compact Separators for de-oiling and de-sanding
» First injection of produced water for reservoir pressure maintenance above fracture pressure

Courtesy of FMC
Subsea Raw Seawater Injection

CNR: Columba E (Ninian) in operation since 2007, Framo: filtration 80 µm particles, 35 MBPD pump(s) at, 480’ WD, 350 bar DP

Petrobras: Albacora 1300’ WD, 120 MBWD, Framo: filtration 80 µm particles 40 bar DP

Statoil: Tyrihans 900’ WD: Aker strainer and pumps installed at 90 MBPD rate, 150 bar DP
Gas-lift not Gaining Traction

• Flow assurance issues related to gas-lift
  – Formation of asphaltenes, scale, wax or paraffin
  – Undersaturated crudes
• Models are not competent
  – Inadequate for high pressure gas-lift applications
  – Inadequate for dealing with undersaturated crude
• Extremely high intervention cost
  – For subsea wells on the order of $25-$48 MMUSD
• Raises GVF lowering seabed pump efficiency
Gas-lift not Gaining Traction

- Integrity of gas-lift equipment
  - Bellows systems
  - Check systems
  - Packing / elastomers
  - Manufacturing and quality systems
- Vendor R&D funding focused elsewhere
- Users are may not be willing to share the cost of development
Sweet Spot for Gas-lift

• Deep formations beyond seabed
  – Perforations at 15,000 – 25,000 ft below seabed

• Column of fluid weight kills well so in-well lift is critical to economical development
  – Two in-well lift systems have been reviewed
    • Deep set ESPs
    • Gas-lift

• Gas-lift is current leader
  – Technology gap is not as great as for the ESP
Side-pocket Mandrels

- **Materials available for H₂S and CO₂ service**
  - 718, 925, 945, etc

- **Design process**
  - FEA
  - Strain gauge testing
  - Max fiber stress

- **Operating envelope**
  - Minimum failure at least equivalent to the tubing minimum failure
  - Test pressure
  - Working pressure

- **Quality control**
  - Almost aerospace
  - Cost of failure is upwards of $75mmUSD
Flow Control Devices

- Bellows life cycle
  - API 19G2 V1 Bellows life cycle testing is beginning
  - Appropriate sample size
  - No concrete results

- Check system
  - Use the Statoil TR2385 testing requirement
  - Failures reported

- Elastomers or Non-Elastomers
  - Comprehensive design validation testing

- Quality control
  - Almost aerospace
  - Cost of failure is upwards of $50mmUSD
Conclusions

• Gas-lift offers excellent choice:
  – For very deep wells
  – Lower initial cost
  – In-well lift improves total recoverable oil

• Gas-lift obstacles to overcome:
  – Intervention cost
  – Products not proven
  – Historically not for high integrity wells
  – High GVF impacts seabed boosting
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