LoSa\textsuperscript{\textregistered} EOR into the Clair Ridge Project
- Laboratory to Day One Field Implementation

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Summary

• In October 2011, BP and co-venturers approved the Clair Ridge development, including LoSal® EOR.

• The Clair Ridge project is the first sanctioned offshore application of LoSal EOR in the industry.

• The project includes membrane desalination plant to deliver 145 mb/d of reduced salinity water.

• Key learnings
  − Extensive core measurements useful
  − Simulation process developed for EOR performance prediction
  − EOR benefit will be delivered with all produced water reinjected
  − All components of membrane systems for delivery of desalinated water were previously deployed & ready for installation/operation

LoSal® is a registered trademark of BP plc
Clair Ridge Field Overview

- Clair is largest oil accumulation on the UKCS, OIIP > 6 billion barrels
- 142 miles north of Scottish mainland, in 132-155 m of water
- Devonian sandstone reservoir, ~50 mD average, 3.2 cP / 24° API oil
- Extended well test (1996) showed well connected fracture network
- Over 5 years of production data (Clair Phase 1) indicate oil displacement via
  - Viscous sweep,
  - Gravity drainage, and
  - Imbibition from the fracture network into the matrix
- Gas flooding, CO₂ flooding, and polymer flooding considered, rejected
- Enhanced waterflood (LoSal EOR) was seen as best option
  - Able to sweep matrix between fractures,
  - Natural water imbibition into Clair rock,
  - Improved unit displacement with reduced salinity
What is LoSal EOR?

- LoSal EOR is enhanced oil recovery via waterflooding sandstones with water that has < 2000-8000 ppm TDS
- Mechanism for release of additional oil inferred from laboratory tests
- Membrane prefiltration/ desalination is most suitable proved technology for use with sea water offshore
Robust Lab Analysis

- Rock from main field area and Clair Ridge tested at reservoir conditions with live fluids
- Significant benefit seen for secondary LoSal EOR application
- Clair Ridge clay content similar to main field core
- Testing done to understand potential for damage with reduced salinity injection

<table>
<thead>
<tr>
<th>Core Source</th>
<th>Delta S_{orw}</th>
<th>% Incremental Recovery (over High Salinity Coreflood)</th>
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<tbody>
<tr>
<td>Clair 1 A02 ~25md</td>
<td>0.055</td>
<td>9</td>
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<tr>
<td>Clair 1 A02 ~100md</td>
<td>0.079</td>
<td>13.1</td>
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</table>
• Sector modelling provided an efficient prediction process
• 48 descriptions developed with possible sub-seismic fracture descriptions
• High salinity and reduced salinity waterflood modeled
• Positive LoSal EOR recovery seen in 98% of reservoir descriptions
Upscaling

- Delphi analysis performed to volume weight field-wide response to sector model results

- Project aim to re-inject 98% of produced water
- Water injection strategy: optimize LoSal EOR recovery within this constraint
- Injection of reduced salinity and produced water into reservoir segments to maximize secondary LoSal EOR recovery and supplement with tertiary recovery

Clair Ridge LoSal Flood Segments

- 56% OIP Secondary
- 27% OIP Tertiary
- PWRI (No LoSal)
Technology Readiness Assessment
• Workshop to assess maturity of membrane technologies and their integration into injection systems
• All equipment components seen to have high levels of readiness for deployment in LoSal EOR facilities

Risk assessment / mitigation
• Assessment applied to water treatment technologies and their integration and operation
• Risks identified assessed for likely frequency and consequent severity, with and without mitigation
• Post-mitigation risk manageability assessed
• Most additional risks due to LoSal EOR implementation seen as low/medium impact or frequency
• High impact risks seen to be managed by design decisions
Claire Ridge LoSal EOR Facilities Feasibility and Topsides Impact Risk Management

Changes
- Membrane water treatment added
- Additional hypochlorite generation
- Increased sea water lift pumps
- Additional manifolding and pumps
- From 2 x 50% to 4 x 25% injection pumps

Impacts
- Additional mezzanine deck
- Footprint increase: 700 m²
- Weight increase: ~1000 tonnes
- Power increase: ~6 MW

Feasible within topsides/jacket design
Relatively modest capex impact
Key Learnings

• Extensive core measurements useful
  – Quantify recovery
  – Confirm imbibition mechanism
  – Define salinity range to avoid reservoir damage
• Recovery predicted for fractured Clair Ridge consistent with other BP fields
• Simulation process developed for EOR performance prediction, from fracture-dominated to matrix-dominated mechanisms
• EOR benefit will be delivered with all produced water reinjected
• All components of membrane systems for delivery of desalinated water were previously deployed & ready for installation/operation
• Interaction among BP and with Clair Ridge co-venturers effective in developing shared understanding of benefits & risks
BP’s *LoSal* EOR –
From Promise to Reality

- In October 2011, BP and co-venturers approved the Clair Ridge development, including *LoSal*® EOR.
- The Clair Ridge project is the **first** sanctioned offshore application of *LoSal* EOR in the industry.
- Project includes membrane desalination plant to deliver 145 mb/d of reduced salinity water.
- Clair Ridge project will be the first sanctioned offshore application of *LoSal* EOR in the industry.
- *LoSal*® EOR is part of BP’s suite of advanced *Designer Water*® technologies developed to increase the oil extraction recovery factor.

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