Shell’s EOR Journey: Experiences past to present

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Outline

- Shell’s EOR Journey
- Maximising economic recovery
- EOR challenges and enablers
- Onshore to offshore
- Offshore CO$_2$ EOR
- Conclusions
EOR journey - Learning by doing

Steam trials

Thermal EOR pilots

Full scale CO₂ floods. Thermal growth.

CO₂/thermal optimisation. Gasification.


Steam injection, Peace River Canada. Miscible gas floods, Oman.


Gas injection. Oil saturation measurement.

1st commercial steam drive. First successful CO₂ field test.

Permian CO₂ boom. Chemical trials. Sour gas injn, Oman

Smart fields. Oil sands.

Polymer injection Oman Steam Assisted Gravity Drainage in fractured carbonate, Oman.

Solar steam, Oman Re-development project, steam injection Schoonebeek, NL
EOR - R&D to Deployment
Polymer flood – Marmul

- Heterogeneous clastic reservoir - 90 cp oil
- Large scale polymer flood on-stream 2010
  - 17,500 m³/day (polymer)
  - Low salinity injection water (5000ppm TDS)
  - 27 patterns
- Oil Increase/Water cut reversal observed
- Produced polymer can be handled
- Increase from 27 → 46 injectors since May 2015
- Urban planning, rotation schedule prepared for full field implementation
Steam Injection – Belridge and Aera

- Belridge Tulare core of Aera, STOIIP 1.6 bstb
- Started production 1911, water drive reached watercuts above 90% before conversion to steam flooding
- Large scale steam injection began 1982
- Ongoing conversion of deeper reservoirs from waterflood to steamflood
- Manages a stock of some 15000 wells at an average production rate of <10bopd.
- In current environment Aera still able to make a profit
**CO₂ EOR – Denver Unit**

Largest CO₂ EOR project in the world, developed by Shell

- more than 400 MMscf/d sustained CO₂ injection in >100 patterns
- over 200 MMscf/d gas processing/recycling on site
- surveillance and management of CO₂ EOR
EOR projects in Oman

PDO Oman

- Actual production
- Assumed production with continued decline

Production decline halted
- Focus on up-time
- Reservoir development
- Sub-surface dynamics
- Innovative EOR schemes

THERMAL PROJECTS
- Fahud SAGOGD
  - Steam Assisted GoGd, Oil, or Waterflood or Surfactant
- Qarn Alam Steam
  - Steam in fractured Carbonates
- Habur & Al Ghubair
  - GA Type Steam in pressurized Carbonates
- Habhab
  - Thermal Field test
- Amal E&W & Mukhaizna
  - Conventional Heavy Oil Steam

MISCIBLE GAS PROJECTS
- Al Noor
  - Miscible Gas or Deep De-Pressurization
- Harweel
  - Miscible Gas or Nitrogen/CO₂
- Birba
  - High pressure sour gas injection

CHEMICAL PROJECTS
- Yibal/Lekhwair
  - Surfactant/ASP
- Nimr & Amin
  - Polymer
- Marmul, Rima & RTQ
  - Polymer/ASP

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Maximising economic oil recovery

- A field with 35% ultimate recovery leaves almost twice as much oil in the ground as we have produced.
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The EOR challenge and enablers

EOR is not business as usual, it is hard work technically and commercially

- Less oil to go after
  - 10-20% EOR incremental, vs 30-60% primary/secondary recovery
- Slower response times
- More expensive injectants
- Requirement for more surface facilities with added complexity

Enablers

- Lifecycle planning and surface subsurface integration
- Step up in surveillance capability to drive performance
- Contracting and procurement framework and standardisation
- Excellent stakeholder management
- Appropriate fiscal and regulatory structures needed
EOR systems: Integration

- Integration of subsurface and surface underpins successful EOR projects
- Work on full injection/production cycle
- Injection system to achieve injectant at design specification in reservoir and flexibility to optimise EOR performance
- Production system robust to changes in fluid streams through EOR project lifecycle
EOR reservoir surveillance

**Fahud – Thermal Gas Oil Gravity Drainage**
- Caprock integrity
- Interpretation of microseismic events
- Traffic light classification
- Geomechanical modeling to support interpretation
- Steam front conformance
- Geomechanical inversion of deformation data

**Amal – Steam Drive**
- Steam front conformance: Integrated interpretation of seismic, petrophysical (log) and geological data
- Understanding of preferential steam direction caused by intra Haradh channel system

**Marmul – Polymer Injection**
- Fracture monitoring and control
- Classification of wells in traffic light surveillance priority
- Well test interpretation
- Calibration and modeling leading to water treatment decisions

**Greater - Birba Miscible Gas Injection**
- Gas inflow monitoring
- DTS feasibility and design

Steam Distribution and Caprock Integrity Monitoring

Steam Distribution Monitoring

Temperature Logging

Frac Length Monitoring

Pressure fall off test – Identification of Polymer Front

FracIT Modelling of frac length

Integrated Interpretation of all data

Steam outline Constrained by data
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Moving EOR offshore

Additional challenges for offshore EOR compared to onshore EOR

- Wider well spacing and slower reservoir processing rates
- Limitations on weight and space for additional facilities or storage
- Impact of EOR injectants on wells/facilities (corrosion, non-metallic materials)
- Impact of wells/facilities on EOR injectants (corrosion products, shear)
- Design life of facilities
- Surveillance challenged, especially for sub-sea wells

Approaches

- Day 1 EOR implementation
- Lifecycle planning to create future EOR optionality
- Brown field modification, potentially supported by additional jackets or vessels
- “Greenfield” EOR redevelopment with new facilities fit for 30+ years production
## Status of Shell offshore EOR

<table>
<thead>
<tr>
<th>Method</th>
<th>Onshore</th>
<th>Shallow water</th>
<th>Deepwater</th>
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<tbody>
<tr>
<td><strong>Thermal</strong></td>
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<tr>
<td><strong>Low salinity waterflood</strong></td>
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<td><strong>Polymer</strong></td>
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<tr>
<td>(Alkaline) Surfactant/Polymer</td>
<td>Producing pilots</td>
<td>Single well test</td>
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<tr>
<td><strong>Miscible Hydrocarbon Gas</strong></td>
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<tr>
<td><strong>Miscible CO₂</strong></td>
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- **Operating/ In execution**
- **Concept selected**
- **Pre-feasibility**
- **Technology demonstration**
St Joseph field: Surfactant polymer flooding for offshore

- St Joseph field identified as target for chemical EOR
- Full field ASP concept feasibility assessment
  - Water treatment and logistics were large cost and operational challenge
- Shift development concept to SP
  - No need to remove divalents from water, but at expense of higher concentration of polymer and surfactants
  - Proved in a SWCTT that SP has the same oil recovery efficiency as ASP
- Can only make things work by working them in detail
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Offshore tertiary CO₂ EOR

- Shell has been active in pushing next generation CO₂ EOR projects
- Studies show offshore CO₂ EOR can be technically and economically feasible
- HSSE brings new issues
- Subsurface-surface integration key
- Innovation needed to simplify facilities and reduce CAPEX and OPEX
- Commercially attractive projects require:
  - Reservoirs with large enough EOR prize
  - CO₂ supply (volume and price)
  - Supportive regulatory and fiscal regimes

“Brownfield” Halten value chain
CO₂ HSSE offshore

Safe operation first priority

- Significant experience of CO₂ operations for onshore EOR projects
- Operation of CO₂ EOR offshore will introduce new set of challenges
  - Inventory, pressure, confined spaces, evacuation
- Shell CO₂ release testing programme to evaluate and validate hazards consequence models

Plant to beach valve
100-1000 t CO₂

Export Pipeline to boarding valve
~10000 t CO₂

CPF platform
~ 50 t CO₂

Injection flow-lines
Production lines
~ 500 t CO₂
(H₂S, CH₄)

WHP platform
~ 100 t CO₂
(H₂S, CH₄)
Key messages

Shell has pioneered EOR technology and continues to innovate to improve existing commercial processes, mature new technology and expand the range of application

- Commercially proven EOR solutions exist for onshore application
  - Technically robust
  - Appropriate regulatory frameworks
- Pushing the envelope of EOR deployment by looking to offshore applications
  - Significant technical and commercial challenges
  - Subsurface-surface integration key
  - Most progress made with gas based EOR in shallow and deep water environments
Shell Integrated CO₂ gas lift system

- Alternative to ESP systems
- Use CO₂ for lift gas, insert string or dual string to protect casing from corrosion
- Lift gas rate adjusted in response to changes in back produced gas

Advantages

- Simple and robust system using recycle system, only modest increase in capacity needed
- Intrinsic risk management, flexibility over number of wells to be gas lifted and response to gas breakthrough timing
- Reduced requirement for well workovers
Three IOR/EOR questions: Where, Why and How?

Redevelopment options need to be based on a proper understanding of the location of the remaining oil saturation

- Describe the location of the remaining oil (after depletion or waterflooding)
- Interpret reservoir performance to understand interplay of geology and balance of viscous and gravity forces
- Infill drilling, waterflood, throughput, deployable EOR processes