Making EOR work

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Agenda

• The Energy Challenge
• EOR technologies, trends and challenges
  • Chemical
  • Gas
  • Thermal
INFLUENCING TODAY’S ENERGY WORLD

Energy Challenge
- Rising Demand
- Supply Security
- Climate Change

Emerging Science
- Biotechnology
- Connectivity & Computing
- Nanotechnology

Value Opportunities
New Entrants

THE ENERGY CHALLENGE

Rising global energy demand
100 = global primary energy demand 2000

Changing energy mix
Million barrels oil equivalent per day

- Coal
- Gas
- Oil
- Nuclear
- Large Scale Hydro
- Alternative Energy

* Shell estimates
Long-term oil-supply cost curve

Hydrocarbon Supply

Source: IEA outlook 2008

it costs more to produce and will be CO2 intensive

World oil production - IEA Reference Scenario

Even if oil demand was to remain flat to 2030, 45 mb/d of gross capacity – roughly four times the capacity of Saudi Arabia – would be needed just to offset decline from existing oilfields

Source IEA 2008
Prices Volatile - Cost Pressure

Cost Escalation vs. Crude Price

Index (100 in 2000)

Brent

Upstream Cost Index

Brent $/bbl

2000 2001 2002 2003 2004 2005 2006 2007 2008 2009

Production Well
Producing Hydrocarbons

Injection Well
Maximizing production

Injection facilities
Source of water
Treatment before injection

Production Facilities
Monitoring the Process

Water Injection as most common development strategy

Production Well
Producing Hydrocarbons
The key issues to be resolved to maximise recovery

**Residual oil saturation**
Often around 20-30% of oil left trapped

**Sweep efficiency**
- Bypassed zones due to well placement
- Fingering due to viscous oil
- Thief zones by heterogeneity

Maximizing Recovery – Average Recovery Factors

Average RF's: Some fields at 65%
Some fields at 10%

Based on current Waterflood technologies

“aspiration”

% Original Oil In Place
EOR Processes

Selection of best technique needs detailed reservoir modeling and analysis.

EOR Value Drivers

- Thermal
  - Heat Placement
  - Steam Generation Cost & Carbon Footprint
  - Thermal Well Cost
  - Surveillance & Data Management

- Miscible Gas
  - Gas Capture/Separation & Integrated Value Chain
  - Infrastructure Usability
  - Conformance & Sweep
  - Subsurface-Surface Integration, Surveillance

- Chemical
  - Chemical Formulation & Utilization Per Barrel
  - Supply Cost & Logistics
  - Waterflood Performance
  - Operational Excellence (Inj QC & Prod Handling)

* Indicative UTCs - Actual project UTCs and breakdown splits will vary
**EOR current Production**
3 mln bbls/day worldwide

- **USA**: 84%
- **Canada**: 7%
- **Turkey**: 3%
- **Others**: 7%

- **CO2**: 10%
- **Pol/Chem**: 10%
- **HC**: 22%
- **N2**: 17%
- **Steam**: 41%
- **North America**: 56%
- **Indonesia**: 18%
- **Venezuela**: 13%
- **China**: 12%
- **Others**: 1%

Source: 2006 OGJ Survey

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**Shell Enhanced Oil Recovery projects**

- 11 EOR projects in construction/operation
- 20 EOR field projects/studies underway
Many Oil Companies are active in EOR

Some important projects to mention from outside Shell:

- Alaska
- Western Europe
- China
- Iran
- Algeria
- Angola
- Neutral zone
- Indonesia
- Venezuela
- Mexico
- California
- Texas
- Neutral zone

Trends

- Gas EOR
  - We can now transport gas through LNG and GtL
  - Too valuable to inject and use as drive fluid
  - Other gases still interesting: CO2, H2S
  - Key aspects are interaction gas/oil, impact geology & costs
- Thermal EOR
  - Often the only solution to heavy oil volumes, e.g. Canada, Venezuela, California
  - High CO2 footprint: CCS becomes integrated part of project
  - High cost oil
- Chemical EOR
  - Less capital intensive, less CO2 footprint
  - Add on to current water floods
  - Issues on stability and disposal
## Chemical EOR

<table>
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<th>Low Salinity options</th>
<th><img src="image1" alt="Low Salinity options" /></th>
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<tr>
<td>Polymer flooding</td>
<td><img src="image2" alt="Polymer flooding" /></td>
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<td>Surfactant flooding</td>
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<td>Enhanced Alkaline Flooding</td>
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<td>Foam enhancements</td>
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## History pre-2000

- USA Multiple ASP tests (since 1960)
- Discovery of the Enhanced Alkaline Flooding process (now know as ASP)
- Pilots, pioneered by Shell Oil in 1980’s

Polymer Flood Research (1980’s)
Successful Pilot tests in Oman
Current Chemical EOR Activities in Shell

- **Oman**
  - Polymer flooding in the Marmul Field
  - Other polymer projects being evaluated
  - Multiple ASP flooding single well pilots in planning phase

- **Rest of the world**
  - Designer Water single well test and projects in sandstone
  - Series of ASP pilot tests in design phase
  - Other polymer projects being evaluated

- **Shell Chemical**
  - Delivery of chemicals to many areas

Low Salinity Flooding

Wettability correlates to water and oil relative permeability

- How about carbonates?
- Impact of these mechanisms on other EOR techniques
Polymer flooding

- Benefits:
  - Improved microscopic displacement due to displacement instability
  - Improved robustness for heterogeneous reservoirs

- Offshore: low demand on weight, space and logistics

Partially Hydrolyzed Polyacrylamide

Salinity sensitive, viscosity of solution depends on shear
**Polymer flood** (starts early 2010)

polymer mixing: 15 cP polymer solution to 27 patterns

**Enhanced Oil Recovery** in Oman

**Recover Residual Oil with surfactants**

Ratio viscous to capillary forces:

\[ N_c = \frac{K}{\sigma} |\nabla P| \approx \frac{\mu \cdot \nu}{\sigma} \]

Typical waterflood for light oil

\[
\begin{align*}
\nu &= 1. \text{ ft/day} \\
\mu &= 0.001 \text{Pa.s} \\
\sigma &= 0.03 \text{ N/m}
\end{align*}
\]

\[ N_c = 10^{-7} \]

To improve
you need > 3 orders increase in \( N_c \)

Reduce interfacial tension
(by adding surfactants)
Typical Surfactant Flood...

Flow direction

- Injector
- Chase water
- Taper
- Mobility Buffer
- Surfactant Slug
- Preflush
- Producer

Polymer to displace micro-emulsion

Polymer Additives

- polymer

Micro-emulsion

High viscosity

ASP
Alkaline-Surfactant-Polymer

Polymer:
- increase viscosity
- improve mobility control and sweep.

Surfactant
- mobilize residual oil.

Alkaline:
- high pH of 11
- natural surfactants (soaps)

Carboxylic acids
- react with water

Carboxylates - surfactants
- form emulsion
**ASP Single Well tests: Positive Results**

**Conclusion:** Significant reduction in residual oil saturation ($S_{or}$) with ASP
- $S_{or}$ after WF ranges 20 – 30%
- $S_{or}$ after ASP 0 - 2%
- Displacement of 90+% remaining oil confirming core flood results
- 2010 progression to pattern trials

**ASP Critical Success Factors**

- Delivering Integrated Know-how
- Surfactant chemistry for cost effective molecules that mobilize oil
- Operational Excellence (e.g. emulsions, WRM, & HSE)
- Cocktail Design & Injection
- Performance Prediction & Surveillance
- Scale and Logistics to produce & deliver large high quality volumes
- Petrochemical products
- Supportive commercial terms
Challenges for Chemical EOR

- Proper injectivity
- Stability of polymer over lifetime of project
- Discharge of produced fluids, Opportunities for re-injection
- Large volumes and costly logistics

R&D
- Extent to higher temperatures and salinities
- Shear behaviour: shear thickening versus shear thinning \rightarrow new materials e.g. associative molecules??
- Bio-degradability
- Improved surfactant selection process using less chemicals
- Reduce IFT without creating emulsions

Gas EOR

- Miscible gas drive, CO$_2$, WAG
- Foam diversion
- (thermal) GOGD
- Air injection
- Alternative gas injection
Gas Flooding, History pre-2000

- Shell E. Texas Gas Injector (1945)
- Brent Miscible Gas development (1985)
- Shell Denver Unit (1995)

Current Gas EOR activities

- **Miscible gas drives**
  - Kashagan EP450 [Kazakhstan]
  - Harweel [Oman]

- **GOGD**
  - Fahud & Natih
  - Thermally Enhanced GOGD

- **Flue gas or Air injection**
  - Pilot design

- **Studies for CO2 sequestration**
  - In USA, UAE, North Sea, Big thermal projects
CO2 Miscible Gas Injection
Taking a Game We Know into the Future

- Proven Technology
  - 30+ years experience
- Difference for the Future:
  - Anthropogenic CO2
  - Carbon Capture and Storage alternatives
- Next Wave Integration
  - Source-Sink frameworks
  - Cost reductions
  - Recovery improvements

West Texas CO2 flood Recovery factors

- High RF is achievable
- Requires good secondary development
CO2 EOR: Matching sources with sinks

CO2 sources
- Refinery Processes and H.O. Upgraders
- CO2 rich Gas Devts
- Coal/Gas Fired Power Plants
- Steel, cement etc
- GtL and CtL

CO2 sinks
- Storage in aquifers & depleted fields
- Enhanced Oil Recovery (EOR)
- Enhanced Coal Bed Methane (ECBM)
- Sub-/surface Mineralisation
- Sales to Industry & Greenhouses

Link to power generation options

Shell-MHI alliance, Mongstad, Cansolv
Shell gasifier
Shell R&D Chemical Looping
CCP Joint Industry Project
Shell R&D Cryocell, C3SEP, SAPO
Giant, Quest, Barendrecht etc
Harweel Gas Injection Project

South Oman
Deep carbonates in salt

Key aspect is to adjust injected gas composition per target field

Using foam to improve sweep and lower Sor

- Miscible

- Miscible & Foam

Especially for CO2 – linked to CSS