SPE Distinguished Lecturer Program

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EOR – The Time is Now
Its Contribution to World Oil Supply

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Enhanced Oil Recovery (EOR) – The Time is Now

Churchill once said:
“the best time to plant a tree is twenty years ago. The second best time is now.”

In E & P, the best time to plan and begin implementation of EOR is during original development planning.

The second best time is Now!
Outline

• Status and potential of EOR
• Why EOR?
• What’s new – Technical
• Why now?
• Planning for EOR
• EOR Opportunities and Challenges
  – Both offshore and onshore
  – Economic
  – Political
• Summary
• 74 million b/d of capacity additions needed by 2030
• 5 million b/d is forecast to be supplied by additional EOR in 2030
• 20 million b/d is from “fields yet to be found”
World Oil Production Forecast (IEA) 2010

- 70 million b/d of capacity additions needed by 2030
- Additional EOR not included as a separate category
- 20 million b/d is from “fields yet to be found”
World Conventional Oil In-Place, ~ 9 Trillion Barrels

Of the 9 trillion barrels in place, ~ 1.1 trillion barrels has been consumed.

33% recovery efficiency

EOR target of 2.2 trillion barrels in discovered fields!
US EOR Production since 1986: ~6.4 billion barrels!

U.S. EOR production is ~12% of the U.S. total

Two major contributors:
Thermal recovery using steam injection
Carbon dioxide miscible recovery

From OGJ biennial surveys
EOR Production outside the US since 1998: ~ 5.5 billion barrels!

Thermal recovery in Venezuela, Indonesia, China, Canada.

Gas injection in Canada, Venezuela, and Libya

Chemical/polymer applications in China.

From OGJ biennial surveys
EOR Methods Based on Lithology

This plot is based on 1507 worldwide projects

Source: SPE 130113, Manrique E., et al; April 2010
Why EOR?

- Access to new exploration acreage is difficult and expensive
- There is significant oil in place in discovered reservoirs that will otherwise not be recovered
- EOR can make an important contribution to world oil supply in the long term
- EOR economics can be attractive
EOR Today

- Mature technologies:
  - Thermal
  - CO$_2$ miscible

- Technologies with unrealized potential:
  - Chemical
  - Polymer
  - Combustion

- Barriers:
  - Long lead times
  - Economics
  - Politics
Not your Grandfather’s EOR (1)

What is new in Mobility Control:

Polymers:
- PetroChina has made significant advances in the design and manufacture of polymers
  - Narrow range of molecular weights
  - Tailored to application
  - Can be applied economically in lower permeability formations
- In-depth diversion technology
  - Thermally activated plugging agents
- Foams
  - Advances in the laboratory
Not your Grandfather’s EOR (2)

What is new in Chemical Flooding:

• Advances in surfactants:
  – Thermally stable surfactants (e.g., sulphonates) remove temperature restrictions
  – Surfactants designed to be active at 0.1% concentrations
  – Sacrificial agents (e.g., sodium carbonate) reduce adsorption to very low levels

• Alkaline flooding:
  – Alkaline-polymer (AP) and alkaline-surfactant-polymer (ASP) are new, lower-cost EOR methods
Not your Grandfather’s EOR (3)

What is new in Thermal Recovery:
• Controlled Combustion – THAI (Toe to Heel Air Injection)
  – Removes depth, pressure restrictions of steam
  – Applicable to light oils
Not your Grandfather’s EOR (4)

What is new in Thermal Recovery:
• **Steam-Assisted Gravity Drainage (SAGD)**
  – Uses horizontal wells to contact formation, reduce well costs
  – Modification of steam drive
What’s New in Tools and Techniques (1)

More efficient project design and management is possible using:

Real-time information gathering, analysis …
What’s New in Tools and Techniques (2)

Horizontal wells …

Smart wells, multilateral wells …
What’s New in Tools and Techniques (3)

Permanent downhole monitoring using fiber optics – pressure, temperature, multiphase flow rate …
What’s New in Tools and Techniques (4)

4-D seismic …

Etc, etc …
Promising Technologies

• Microbial EOR
• Nanotechnologies
  – Smart tracers
  – Delivery of materials
  – Detailed reservoir description
• Down-hole steam generation
Why Now?

- Design and implementation of an EOR project takes time
- After implementation (especially as a tertiary project) production response does not occur immediately
Steps to a Successful EOR Project (1)

• Field selection
  – Successful secondary?
    • A water-based EOR process will go where the waterflood water went
  – In-place target
    • Is there sufficient remaining oil in place to justify an EOR project?
Steps to a Successful EOR Project (2)

- Process selection: what is the objective?
  - Improved sweep efficiency
    - Overcome reservoir heterogeneities or poor mobility ratio
  - Improved displacement efficiency
    - Is the objective to recover a residual oil saturation in a swept zone?
Steps to a Successful EOR Project (3)

Reservoir Modeling
- Analog Data
  - Analytic Tools
  - Coarse Simulation
  - Fine Simulation

Engineering Data
- Field Selection
- EOR Process Selection
- Geologic Studies
- Design Parameters
  - Lab Data (R&D)
  - Field Date
- Pilots / Field Testing
- Project Implementation

Economics
- Screening
- Detailed Economic Models
Pilot Testing

- Use to reduce critical uncertainties
- Most expensive, most time-consuming
- Design with specified objectives
  - Oil-in-the-tank not sufficient
  - Profitable pilot usually unrealistic
- Need dedicated personnel
Types of Pilot Test

**Single Well**
- inj

**ROS Determination**
- Injectivity

**Single Five-Spot**
- prod
  - + Displacement efficiency
  - + Sweep efficiency
  - + Operations experience

**Mini-Test**
- obs

**Confined Five-Spot**
- + Build oil bank
- + Vertical, Areal conformance

- + Redundancy
- + Improved capture efficiency
EOR Project Time Line

- Initial Response
- Implementation
- Pilot Testing
- Design Parameters
- Geologic Studies
- Process Selection
- Field Selection

Years:
- 0
- 2
- 4
- 6
- 8
- 10
Opportunity:

• Target resource for EOR applications is 6 trillion barrels, of the 9 trillion initially in place
• Widespread application could far exceed the current forecasts
• Chemical / polymer flooding has large unrealized potential
• Both hydrocarbon and CO2 miscible flooding have large potential internationally
• A significant resource exists in the offshore, as well as onshore
• CO2 sequestration may provide an additional impetus and opportunity
EOR Challenges

However, there are significant challenges:

• Application Onshore:
  – old wells,
  – commingled wells,
  – reservoir understanding

• Application Offshore:
  – large well spacing,
  – logistics,
  – reservoir understanding
Economics Challenges

• Thermal:
  – Greenhouse gas emissions
  – Combustion - perceived high risk

• Chemical – Polymer
  – Long lead times, long payout
  – Perceived high risk

• CO$_2$ Miscible
  – Access to CO$_2$

However: Long term demand and price increases present opportunities!
Political Opportunities

• NOC, IOC, Governmental Relationships can harm EOR opportunities:
  – Mutual interests are hampered by short-term considerations, different objectives

• Solution: treat EOR differently!
  – Jointly share technical, economic risk
  – Revise concession terms to include life-of-project for EOR
Finally, carbon capture initiatives may present an economic opportunity for increased recovery

- Joint industry-government efforts to gather CO$_2$ for sequestration
  - Examples: North Sea, U.S. GOM, Middle East
    - Large volume in developed fields in the subsurface
    - Opportunity for collection of CO$_2$ (power plants, petrochemical facilities), delivery to offshore fields

- These opportunities may not be practical for an individual oil company, but are feasible with a joint industry-government approach
North Sea Example (1)

Some Regional CO₂ Sources

- Gullfaks
- Longstad, 2.2
- Kårsto, 0.2 +
- Brae
- Sleipner
- Grenland, 0.5 – 2
- Ålborg, 3 + 2
- Esbjerg, 2.0
- Enstedværk, 3.0
- Brunsbüttel, 0.65
- Antwerp/Rotterdam, 2–3
- Melkøya, 0.7
- Drax ~9.0

H. Agustsson, StatoilHydro, SPE ATCE 2008, Denver
North Sea Example (2)

Two Supply Alternatives, 5 Mt/year

Supply Scenario I
- Single Source
- CO₂ capture from two Danish coal-fired energy plants
- CO₂ transport by pipeline to field or ship to Norwegian CO₂ Hub

Supply Scenario II
- Multi Source
- Snøhvit Hydro (Brunsbüttel) BASF / Air Liquid - Mongstad
- CO₂ transport by ship to Norwegian CO₂ Hub and pipeline to field

H. Agustsson, StatoilHydro, SPE ATCE 2008, Denver
Summary

• EOR Technologies exist that reduce project technical risk
• EOR can make a much more significant contribution to world oil supply than is currently forecast
• EOR is a long-term business
• Cooperation between IOCs and NOCs can result in mutual benefits
• CO2 sequestration presents an additional E&P opportunity

The second best time to plan and begin implementation of EOR is Now!