Delay P&A Through Improvement in Oil Cut for Mature Offshore Facilities

Michael R. Pavia, PhD
Chief Technology Officer

April 28, 2016
Why A Biological Process for Enhanced Oil Recovery?

Improving tertiary recovery; making waterflooding more efficient

Tailored for offshore:
- Higher rate, more recovery
- Limited Opex, Capex, no risk
- Small footprint, simple process
Large returns in declining fields

Rapid adoption in fields currently under seawater flood

Effective over large injector-producer distances and in large, complex zones
Large returns in declining fields

Rapid adoption in fields currently under seawater flood

Effective over large injector-producer distances and in large, complex zones
Offshore P&A costs are very large – $100+ MM

Decisions driven by current and future (unknown) oil prices

Delaying P&A is always better, if economic production can be maintained

Cumulative benefit (NPV10) of delaying a $100MM P&A with a 10% return on capital
Candidate fields: near the economic limit of waterflooding

Multiple EOR methods with different CapEx and R&D costs

Biological EOR - low complexity, low cost option

<table>
<thead>
<tr>
<th>Method</th>
<th>Pre-Project R&amp;D</th>
<th>Capital Expenditures</th>
<th>Time to implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical EOR</td>
<td>Complex, Iterative</td>
<td>High</td>
<td>Years</td>
</tr>
<tr>
<td>Gas Injection</td>
<td>Straightforward, Rapid</td>
<td>High</td>
<td>Years</td>
</tr>
<tr>
<td>Biological EOR</td>
<td>Straightforward, Rapid</td>
<td>Low</td>
<td>Months</td>
</tr>
</tbody>
</table>
AERO: Activated Environment for Recovery of Oil

- Holistic approach to microbial stimulation
- Low-dose chemicals (nutrients) injected
- Enables growth of seawater and reservoir microbes on residual oil
- Microbial activity improves oil mobility and flooding

Diagram:
- Naturally occurring microbes
- Added Nutrients
- Growth & Disrupted oil-water IFT
- Residual oil
- Improved Sweep & Oil Mobility
1. Microbes Grow on Residual Oil
   - Injected nutrients enable the microbes in the reservoir to grow on the oil in the reservoir.

2. Trapped oil is freed
   - Growth of microbes on the residual oil releases additional energy and pressure to more efficiently unlock and drive oil to producing wellbores.
   - More oil flows to the surface
Biological surfactants reducing interfacial tension

SPE 10924 (Kowalewski)
Selective plugging of high-perm zones

- Heterogeneous reservoirs
- Communication between layers
AERO Field Result - Canadian Project

Graph showing the production data over time. The x-axis represents months relative to AERO start, and the y-axis represents the average BOPD. The graph compares Pre-AERO Production, AERO Production, and Pre-AERO Decline.
Statoil’s Norne FPSO was the first offshore biological EOR project. Treated blocks had long water breakthrough time. Overall very low WOR consistent with high sweep efficiency through >100 MMboe.

Adapted from www.force.org (http://goo.gl/8tLbkH)
7-year Statoil-Glori Energy collaboration resulted in development of Glori’s AERO (Activated Environment for Recovery of Oil) Technology

Yielded data from 15 on-shore AERO projects

No negative outcomes – corrosion, MIC and production chemistry all nominal

Two projects were of particular interest with respect to large and complex offshore fields
  Field C – complex, layered geology with long inter-well distances
  Field X – long reservoir cycle time, moderate inter-well distances
**Reservoir Parameters**
Medium to light crude
Layered sandstone system, 200-1300 mD permeability
Four main zones and 16 reservoir units.
Net thickness 25 to 120 feet

**AERO**
6 month pilot yielded up to 130 BOPD, a 40% increase in the targeted area
Field returned to original decline after nutrient injection stopped
Field C – Individual Well Results

8 definitive responding wells – 66 BOPD uplift
Responding wells were over 1000 feet away and up-dip of nutrient injection
Response magnitude and timing unrelated to distance
Reservoir Parameters
26 °API gravity oil
1400 mD, 23% porosity sandstone
Net pay 12 feet
800 feet subsea in depth

Water flood
First water injection in 1993
0.13 PV per year average

AERO
28 months injection
Oil rate increased >4-fold
No new decline
Dramatic improvement in two wells
Producers L-H and W
responsible for 80% of field uplift
Water/oil ratios improved 2 and 3 fold, respectively

Rapid response, independent of transit time
Distinct uplift after 5 months
Injector-producer distances >1300 ft
Only 0.03 pore volume of injection prior to response
**Reservoir compatibility**
- Sandstone, >75 mD
- Hydraulic connectivity
- Down-dip injection

**Fluid Compatibility**
- Oil >20 °API Gravity
- Low-organic content injection water
- Bio-compatible temperatures
- Microbes that grow on oil

![Graph showing microbial metabolic activity over days elapsed for different salinities with and without oil](chart)
Seawater injection → Simple project development
Microbes already present
Unlimited volume of bio-compatible injection water
Reservoir and production analyses use existing data

Minimal CapEx
Injection access point and pump
Nutrient storage (1 bbl nutrient per 4000 bbl injected)

Screening and project design: 2-4 months
1. Seawater Pump
2. Coarse Strainer
3. Ultra filtration
4. SRU Membranes
5. Vacuum deaerator
6. Nutrient Addition
Injection Skid Overview

- Standardized units
- Containerized
- Skid mounted
Controls and Monitoring

- SCADA System
- Satellite/Cellular Signaling
- Remote monitoring and control
Nutrient Manufacturing

- Onshore blender
- Offshore blending (FPSO)
- IBC storage vessels
- ISO Container
Quality Control and Assurance

Ensure water quality, nutrient concentration, oxygen concentration, etc.
Monitor impact on field water injection, water cut, and oil production, etc.

**Pump** (Variable frequency drive (VFD), or programmable logic controller (PLC))

<table>
<thead>
<tr>
<th>Onshore</th>
<th>Offshore</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Water quality</td>
<td>- Pressure, mass flow meters</td>
</tr>
<tr>
<td>- Production monitoring</td>
<td>- SCADA</td>
</tr>
<tr>
<td></td>
<td>- Remote monitoring and control</td>
</tr>
</tbody>
</table>
Delaying P&A with Glori’s AERO Technology

Compatible with low well-density offshore fields
  Large injector-producer distances
  Low injection rates relative to reservoir volume
  Complex reservoirs

Benefits realized rapidly
  Implementation process is simple, rapid
  2-6 month response, depending on nutrient applied
  Quantitative response in 12 months

Uplift and/or reduced decline yields large returns
  Delay P&A
  Produce existing asset(s)

AERO is now available for mature offshore fields
Delay P&A Through Improvement in Oil Cut for Mature Offshore Facilities

4315 South Drive
Houston, TX 77053
Phone: 713.237.8880
info@GloriEnergy.com