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Does Heavy Oil Recovery Need Steam?

Johan van Dorp

35 years with Shell Group - Retired Oct 2016

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Includes technically and economically challenged in-place resources (e.g. low So, thin beds, low net-to-gross, low permeability, immobile oil).

Worldwide HO production is ±10 mln bbl/day (<0.1% p.a. depletion rate), of which 2 mln bbl/day from thermal (steam based) projects (2%-4% per annum depletion).
Total: 2 million Bopd

Note: Excludes production from surface mining in Canada (1,050 kbpd)

Heavy Oil Production - It’s All About the Viscosity

Heavy Oil and Bitumen viscosity varies vertically and laterally.

Usually limited data

MUST REDUCE VISCOSITY TO PRODUCE

HEAT
DILUTE
UPGRADE

Need an accurate fluid model to design and optimize processes

Ref. Adams et al., University of Calgary, 2008
Larter & Adams, JCPT Jan 2008 V47 #1
THERMAL PROCESS EFFICIENCY-CASE FOR ACTION IN LOW CO₂ WORLD

Thermal EOR is Energy Intensive
- Heat mostly rock (~90% of mass)

Key Efficiency Factors
- Reservoir Pressure (determines steam T)
- Resource Richness (14% wt ≈ 20% S₀,φ)
- Reservoir Thickness

CO₂ Footprint > 40 kg/bbl oil (avg. US refinery intake)

Focus on:
- Recovery Technologies
  - Incremental Improvements
  - Step Change Improvements
- Process Improvements
  - Carbon Capture & Storage
  - Solar Steam
EOR Technology Maturity – Application to Heavy Oil

Commercial Technology
- Steam (SF, CSS, SAGD)
- Miscible
- Steam additives (Foam, Solvents)
- Thermal GOGD
- In-Situ Combustion / HPAI
- Alkaline Surfactant Polymer
- Low Salinity Waterflooding
- In-situ Upgrading Process
- Contaminated / Acid Gas inj.
- Joule Heating / EM Heating
- VAPEX / Condensing Pure Solvent

Process Maturity
- In Testing
- Low Maturity
- Novel Solvents
- Cyclic Solvents
- Microbial
- Foam

Time

R&D RECOVERY TECHNOLOGIES – HEAVY OIL & BITUMEN

R&D Focus
- Reduce CO₂ footprint of Heavy Oil and Bitumen recovery
- Unlock stranded Assets
  - Thin reservoirs / Low quality reservoirs
  - Fractured Carbonates
- Mature

Breakthrough Improvements
1. Pure solvents (VAPEX & improvements)
2. Electro Magnetic heating & hybrids (3 types)
3. Polymer
  - Surfactants

Incremental Improvements
4. Solvent assisted (like ES-SAGD)
- Steam foam
- Hybrids (e.g. with In-situ combustion)
- In-Situ upgrading
PURE SOLVENTS

Solvent: “A usually liquid substance capable of dissolving or dispersing one or more other substances”

Dissolve: “To mix with a liquid and become part of the liquid”

Examples of Pure Solvents (Single component):
- Propane
- Butane
- Pentane
- Chloroform
- Ether
- Toluene
- Carbon di-sulfide
- Di-chloromethane
- Etc.

HOW CAN VAPEX BE IMPROVED?

Unsuccessful VAPEX Field Pilots
- e.g. Dover

- Vapour solvent diffusion into viscous HO / bitumen is slow:

\[ D \approx \frac{T_{abs}}{\mu_{bit} r_{solv}} \]

- Methane & NCG (solution gas) “poisons” the process
SOLVENT EXTRACTION USING LIQUID SOLVENT IS FAST

- Bitumen diffusion into liquid solvent is fast: \( D \approx T_{abs} / (\mu_{solv} r_{hit}) \)
- Convective dispersion refreshes solvent front

Solvent is a pure paraffinic H.C. (e.g. C3, C4 or C5)

TECHNOLOGY – CONDENSING SOLVENTS

Technology
- Solvent at 40-60°C instead of Steam
- Fast extraction at Solvent interface
- Upgraded product (less asphaltenes)
- Small inventory (vapour)

Business Impact
(comparison with Steam)
- 5x lower energy & GHG
- Faster than SAGD, similar R.F.
- 50% lower Capex: (no water, no water use)
- Applicable to low So, thinner resource (~5 m)

Commercialisation
- Pilot & Demonstration by Technology Providers
SOLVENT EXTRACTION – FIELD TRIALS

- Nsolv pilot: Bitumen Extraction Solvent Technology
  - SAGD Well Configuration
  - Operate 30-50 °C above $T_{\text{reservoir}}$
  - Faster than Steam Extraction
  - Produce Upgraded Product

- Imperial: Cyclic Solvent Pilot
  - Reservoir Conditions 31 Bar / 19 C
  - Propane + diluent
  - 100,000 to 200,000 bbl/well; 5 cycles
  - Claim to have solution to manage unstable displacement

Ref. AER website, N-solv website
IPTC 18214 Boone et.al

ELECTRIC HEATING


FORMATION ELECTRICAL HEATING – 4 PROCESSES

- Resistive – IUP process (Shell)
- Electro-thermal – (ET Energy)
- Induction – (Siemens)
- High Frequency (RF) – (Harris)

Process – Formation “Joule” Heating (50-60 Hz)

- Drill electrodes wells (around 25 m spacing)
- Apply e-power and pre-heat to 60-110 C
  - 1-2 years at 5A/m, Uniform Heating
  - Produce oil by thermal expansion (5-10% OIP)
  - Produce oil by (Foamy) Solution Gas Drive (15-25% OIP)
  - Produce oil by EOR displacement method

Technology Challenges:
- Electrode Design not Mature
- Cooling of Electrode may be required
- Current Uniformity along Electrode

McGee JCPT Jan 2007, V46 #1
SPE 117470 McGee
POLYMER FOR HEAVY OIL

Polymer for Heavy Oil EOR

Reduce Waterflood Mobility Ratio by increasing Viscosity of Displacing Water (HPAM – Hydrolized PolyAcrylaMide)

- Mitigates Heterogeneity, Stabilises Injection Conformance

Polymer applications for typical Heavy Oil (benign conditions):

- Low Temperature T < 70-80 C
- Low Salinity environment <10,000 ppm TDS
- Medium/High Permeability K > 50 mD
- Polymers available with demonstrated stability at low cost and ease of handling, i.e. HPAM
- Low/Medium Viscosity < 100 cP

CNRL & Cenovus apply polymer at large scale in Pelican Lake / Brintnell field (next slide). They do not target stable displacement.

Research: increase flooding temperature to ~70C instead of 20C
POLYMER FOR HEAVY OIL & BITUMEN (CNRL – BRINTNEL)

- Formation: Whabasca
- Thickness: 3-6 m
- Well Length (I&P): 1500 m+
- Live Oil Viscosity: 900 cP
- Polymer Viscosity: 25 cP
- Breakthrough polymer: 6 cP in 1.5 y

WaterFlood comparison:
- Mobility Ratio: 250 → 10
- Microscopic U.R. @ BT: 21% → 50%

Ref. AER public website
SPE 165234 Delamaide

STEAM + SOLVENTS
EXPANDING SOLVENT-SAGD INDUSTRY MOMENTUM

Finished, ongoing and planned ES-SAGD field tests & LASER

Viscosity Model to Accurately Fit Lab Data
**ES-SAGD RECOVERY MECHANISM**

First drop of water

Solvent evaporation

Solvent condensation and mixing with remaining bitumen

Temperature

HOT STEAM FRONT

MOBILE BITUMEN

IMMOBILE BITUMEN

Bitumen flux

Initial reservoir temperature

**ES-SAGD TIMING OF DILUENT SLUG ADDITION (10%wt)**

Modelling Results

<table>
<thead>
<tr>
<th></th>
<th>cOSR (v/v)</th>
<th>Net Solvent Efficiency (V oil / V solvent retained)</th>
<th>R.F. Diluent (%)</th>
<th>U.R. Bitumen (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAGD</td>
<td>0.21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late Slug</td>
<td>0.28</td>
<td>6.6</td>
<td>93</td>
<td>82</td>
</tr>
<tr>
<td>Early Slug</td>
<td>0.33</td>
<td>6.1</td>
<td>95</td>
<td>83</td>
</tr>
</tbody>
</table>
Reservoir Modelling

Reservoir Simulation Challenges

- Use of 9-pt scheme in Dynamic LGR (local grid refinement)
- Unstructured Grids to reduce orientation effects
- Convective dispersion as a mixing mechanism in miscible displacement
- Very thin solvent interfaces
- Diffusion dependent on (T, c); diffusive flux between phases

- Include Maxwell’s Electromagnetic Equations in Thermal Reservoir Simulator

SPE 141711 Batenburg et.al.
CONCLUSIONS

- Breakthrough technologies and incremental improvements to steam injection result in significant environmental footprint (CO2) reductions
  - Steam Recovery Processes are here to stay, but with 30%-50% efficiency improvements (adding solvents or foam to the steam)
  - Promising technologies aim at lower reservoir operating temperatures to 40-100 °C (polymer flooding; pure solvent extraction; electric heating)

- Some of these technologies are mature and can be selected
  - Pure Solvent Extraction and Electrical heating are being demonstrated.

- Modelling the solvent processes and electric heating processes require significant enhancements to modelling technology

- Vast Heavy Oil resources worldwide (10,000 billion Bbls), but underdeveloped
  - Developments are economically challenged without innovative solutions

Your Feedback is Important

Enter your section in the DL Evaluation Contest by completing the evaluation form for this presentation
Visit SPE.org/dl
### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>CNRL</td>
<td>Canadian natural resources Ltd.</td>
</tr>
<tr>
<td>CWE</td>
<td>cold water equivalent</td>
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<tr>
<td>EM</td>
<td>electromagnetic heating</td>
</tr>
<tr>
<td>EOR</td>
<td>enhanced oil recovery</td>
</tr>
<tr>
<td>GHG</td>
<td>green house gas</td>
</tr>
<tr>
<td>H.C.</td>
<td>hydrocarbon</td>
</tr>
<tr>
<td>HO</td>
<td>heavy oil</td>
</tr>
<tr>
<td>HPAM</td>
<td>Hydrolized Poly AcrylaMide</td>
</tr>
<tr>
<td>NCG</td>
<td>non condensable gas</td>
</tr>
<tr>
<td>NGL</td>
<td>natural gas liquids</td>
</tr>
<tr>
<td>OSR</td>
<td>oil – steam ratio (v/v)</td>
</tr>
<tr>
<td>RF</td>
<td>radio frequency</td>
</tr>
<tr>
<td>SOR</td>
<td>steam – oil ratio</td>
</tr>
<tr>
<td>TDS</td>
<td>total dissolved solids</td>
</tr>
<tr>
<td>U.R.</td>
<td>ultimate recovery</td>
</tr>
<tr>
<td>WP</td>
<td>well pair (in SAGD)</td>
</tr>
</tbody>
</table>

### Recovery Processes

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>CSS</td>
<td>cyclic steam stimulation</td>
</tr>
<tr>
<td>ES-SAGD</td>
<td>expanding solvent SAGD</td>
</tr>
<tr>
<td>GOGD</td>
<td>gas-oil gravity drainage</td>
</tr>
<tr>
<td>HPAI</td>
<td>high pressure air injection</td>
</tr>
<tr>
<td>IUP</td>
<td>in-situ upgrading process</td>
</tr>
<tr>
<td>LASER</td>
<td>liquid addition to steam to enhance recovery</td>
</tr>
<tr>
<td>SA-SAGD</td>
<td>solvent aided SAGD</td>
</tr>
<tr>
<td>SAGD</td>
<td>steam assisted gravity drainage</td>
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<tr>
<td>SAP</td>
<td>solvent aided process</td>
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<td>SC-SAGD</td>
<td>solvent cyclic SAGD</td>
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<td>SCIP</td>
<td>solvent co-injection pilot</td>
</tr>
<tr>
<td>SF</td>
<td>steam flooding</td>
</tr>
<tr>
<td>VAPEX</td>
<td>vapour assisted petroleum extraction</td>
</tr>
</tbody>
</table>

An e-list with ±100 literature references with local SPE section