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Does Heavy Oil Recovery Need Steam?

Johan van Dorp

35 years with Shell Group - Retired Oct 2016
OUTLINE

• GLOBAL HEAVY OIL & BITUMEN
• THE HEAVY OIL RECOVERY CHALLENGE
• NEW TECHNOLOGIES & DEVELOPMENT OPTIONS
• MODELLING CHALLENGES
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).
WORLD HEAVY OIL – THERMAL PRODUCTION (2014)

Total: 2 million Bopd

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

Sources:
- Hart Energy
- Oil Sands Review

Note: Heavy Oil = API < 18 (Hart E&P)
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% $S_o\cdot\phi$)
- Reservoir Thickness

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

- HO Project
Thermal EOR is Energy Intensive
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CO₂ Footprint > 40 kg/bbl oil

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)
- Polymer Flooding
- 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

Faint colour = N/A for HO
Underlined = Lower Energy
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

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
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:

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

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

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

Gravity Drainage Fluxes

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

Ref. Nenniger PETSOC 2008-139
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

Ref. N-solv website
SOLVENT EXTRACTION – FIELD TRIALS

- Nsolv pilot: Bitumen Extraction Solvent Technology
- Imperial: Cyclic Solvent Pilot

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

- 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)

Overburden
Reservoir

Heating by Thermal Conduction

Electro-thermal – (ET Energy)

Overburden
Reservoir

Deep Heating by Ohmic Heating of Formation Water

Induction – (Siemens)

Overburden
Reservoir

CABLE LOOP

Heating by Eddy Currents in Formation Water

High Frequency (RF) – (Harris)

Overburden
Reservoir

ANTENNA

Di-Electric Heating of Formation where Formation Water has Evaporated
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
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
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

- Cold Lake LASER - Commercial
- Condensate ~ 240 wells
- Cold Lake SA-SAGD Diluent
- CL SAP Condensate
- Condensate 5wt%
- Jackfish multiple WPs
- Surmont E-SAGD NGL mix; Ops. Upsets
- Leismer SCIP Diluent
- Great Divide Algar SAGD+
- Condensate
- Firebag - 2 days Diluent
- Peace River Steam Drive Pad19 diluent
- CL CondenSAP Condensate
- Germain SC-SAGD 4WPs
- Long Lake SCI Pad13 2WPs

Success / Fail / Ongoing


Butane

Bitumen Uplift (%) SOR Improvement (%)
Viscosity Model to Accurately Fit Lab Data

Data & model on Bitumen blended with condensate

Viscosity mixing rules based on Walther relationship

M/AARD=Max/Avg Absolute value Relative Deviation
Modelling Results

- Bitumen-SAGD
- Bitumen-Late Slug
- Bitumen-Early Slug
- Abandon @ OSR=0.13
- Solvent R.F.-Late Slug
- Solvent R.F.-Early Slug

<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>
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<td>0.33</td>
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</table>
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
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

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

Recovery Processes

CSS = cyclic steam stimulation
ES-SAGD = expanding solvent SAGD
GOGD = gas-oil gravity drainage
HPAI = high pressure air injection
IUP = in-situ upgrading process
LASER = liquid addition to steam to enhance recovery
SA-SAGD = solvent aided SAGD
SAGD = steam assisted gravity drainage
SAP = solvent aided process
SC-SAGD = solvent cyclic SAGD
SCIP = solvent co-injection pilot
SF = steam flooding
VAPEX = vapour assisted petroleum extraction

An e-list with ±100 literature references with local SPE section
**Abstract:** Heavy Oil recovery traditionally starts with depletion drive and (natural) waterdrive with very low recoveries as a result. As EOR technique, steam injection has been matured since the 1950s using CSS (cyclic steam stimulation), steam drive or steam flooding, and SAGD (steam assisted gravity drainage). The high energy cost of heating up the oil bearing formation to steam temperature and the associated high CO2 footprint make steam based technology less attractive today and many companies in the industry have been actively trying to find alternatives or improvements. As a result there are now many more energy efficient recovery technologies that can unlock heavy oil resources compared with only a decade ago. This presentation will discuss breakthrough alternatives to steam based recovery as well as incremental improvement options to steam injection techniques. The key message is the importance to consider these techniques because steam injection is costly and has a high CO2 footprint.

**Bio:** Johan van Dorp holds an MSc in Experimental Physics from Utrecht University and joined Shell in 1981. He has served on several international assignments, mainly in petroleum and reservoir engineering roles. He recently led the extra heavy-oil research team at the Shell Technology Centre in Calgary, focusing on improved in-situ heavy-oil recovery technologies. Van Dorp also was Shell Group Principal Technical Expert in Thermal EOR and has been involved with most thermal projects in Shell throughout the world, including in California, Oman, the Netherlands, and Canada. He retired from Shell after more than 35 years in Oct 2016. Van Dorp (co-)authored 13 SPE papers on diverse subjects.
I. **Condensing Solvents**

I. **Electrical Heating**

**Joule Heating**

I. Electrical Heating

Induction heating

RF Heating
- http://www.acceleware.com/
I. III. Enhanced Waterflood

**Polymer**
- Delamaide, E., Zaitoun, A., Renard, G., & Tabary, R., "Pelican Lake Polymer Flood - First Successful Application in a High Viscosity Reservoir", EAGE 17th European Symposium on Improved Oil Recovery, St.Petersburg, Russia, April 2013, B33.
- [http://www.snf-group.com/about-us](http://www.snf-group.com/about-us)

**Chemical**
Steam-Solvent Viscosity


General


ES-SAGD


• Dittaro, L. M., Dickson, J. L., & Boone, T. J. (2013, June 11). Integrating the Key Learnings from Laboratory, Simulation, and Field Tests to Assess the Potential for Solvent Assisted - Steam Assisted Gravity Drainage. Society of Petroleum Engineers. doi:10.2118/165485-MS

IV. Steam-Solvent (cont.)

LASER

Steam Drive
V. Steam-Foam


VI. Fractured Carbonates

LITERATURE LIST (9)

VII. Modelling

VIII. Solar Steam
IX. Miscellaneous