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A New Heavy Oil Recovery Technology to Maximize Performance and Minimize Environmental Impact

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Outline

• Global perspective of heavy oil
• Overview of recovery processes
  – Steam-based thermal processes
• Environmental impacts from current heavy oil recovery
• Technology development to meet environmental challenges
  – Hybrid steam-solvent process: from research concept to field pilots
• Conclusions
Heavy Oil

Heavy Oil: Crude Oil with API < 22.3° (sp. gr. = 0.92)

<table>
<thead>
<tr>
<th></th>
<th>API Gravity</th>
<th>Viscosity (cp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy Oil</td>
<td>10° – 22.3°</td>
<td>100 – 10,000</td>
</tr>
<tr>
<td>Extra Heavy Oil</td>
<td>&lt; 10°</td>
<td>100 – 10,000</td>
</tr>
<tr>
<td>Bitumen</td>
<td>&lt; 10°</td>
<td>&gt; 10,000</td>
</tr>
</tbody>
</table>

Total World Crude Oil Resources: 9 – 13 trillion bbls

More than 2/3 of total oil resources are heavy oil and bitumen

Source: 12th World Petroleum Congress (WPC), 1987

Source: International Energy Agency (IEA)
Heavy oil can be found in all continents both on-shore & off-shore except Antarctica.
Global Heavy Oil Reserves

Heavy oil can be found in all continents both on-shore & off-shore except Antarctica

Source: http://www.HeavyOilinfo.com
Global Heavy Oil Production

Canada
- Oil Sands: 1000 KBOPD, API 8-18
- Insitu Bitumen: 400 KBOPD, API 11-20

USA
- Canada Oil Sands: 1000 KBOPD, API 8-18
- Mexico: Cantarrel 2080 KBOPD, API 11-20
- China: 180 KBOPD, API 12-20
- Brazil: 250 KBOPD, API 11-20
- Ecuador: 25 KBOPD, API 14-20
- Colombia: 80 KBOPD, API 12-20
- Trinidad: 55 KBOPD, API 15-20
- Venezuela: 629 KBOPD, API 7-20
- HO Production: KBOPD

Global in-situ heavy oil production ≈ 5 million bbl/day

Source: Oil and Gas Journal Dec 2005; Upstream Mar 2006
Variety of Viscous Oils

Variety of Viscous Oils

10,000,000

ir T Canada

Viscosity Reduction (Add Heat or Solvent)

100,000

1,000,000

at reserv

US Venezuela/Colombia

China

India/Indonesia

Bitumen

Viscosity (cp) at reservoir T

100,000

10,000

1,000

100

10

1

0.1

0 10 15 20 25 30 35 40 45 50

API Gravity

Source: OGJ EOR Survey (April 2004)

There are many ways to recover heavy oil

Primary Production;
Water Flooding; EOR

Viscosity Reduction (Add Heat or Solvent)

Canada

US

Venezuela/Colombia

China

India/Indonesia

US

Canada
Heavy Oil Recovery Processes

Recovery Processes

Surface Mining

Primary
- Cold Production
- CHOPS

Thermal
- Steam-Based
  - CSS
  - Flooding
  - SAGD
- Combustion
  - Fire Flooding
  - THAI

Non-Thermal
- Water Flooding
- Chemical Flooding
- VAPEX

Steam-based thermal recovery processes are most extensively used
Cyclic Steam Stimulation (CSS)

- Single well operation
- Injection/production cycle:
  - Steam injection
  - shut-in (soak)
  - Oil production
- Recovery factor (RF) \( \approx 15\% \) OOIP (original oil-in-place)

Source: http://www.HeavyOilinfo.com
Steamflooding

- Multi-well operation in regular pattern
- Inject steam into one or more wells
- Drive oil to separate producers
- Recovery factor (RF) ≈ 50% OOIP

Source: http://www.HeavyOilinfo.com
Steam-Assisted Gravity Drainage (SAGD)

- Horizontal well pair near bottom of pay
  - Upper steam injector
  - Lower oil producer
- Steam chamber rises upward, then spreads sideway
- Oil drains downward to producer
- Recovery factor (RF) > 50% OOIP

Source: http://www.HeavyOilinfo.com
Steam-Based Thermal Recovery Processes

• Very energy intensive and inefficient

**Thermal Efficiency for Each Stage:**

- **Steam Generator**
  *(75 – 85%)*

- **Transmission to Well**
  *(75 – 95%)*

- **Well to Reservoir**
  *(80 – 95%)*

- **Flow in Reservoir**
  *(25 – 75%)*

**Final Efficiency: 11% - 58%**

• Significant environmental impacts
  - **Land**: Surface footprint
  - **Air**: Greenhouse gas (GHG) emission
  - **Water**: Water usage and disposal

*Source: Butler, “GravDrain’s Blackbook”, (1998)*
Surface Footprint

- Small well spacing for heavy oil
  - less than 10 acres pattern for CSS and Steam flooding

>15,000 wells in ~60 km² (~23 mile²)

Chevron Steamflooding Operation
Kern River, California, USA
Surface Footprint

• Reduce surface footprint with horizontal or multi-lateral wells (e.g., SAGD)

CNRL CSS Operation with Horizontal Wells
Primrose, Alberta, Canada
(62,000 bbl/d)

Reduce Surface Footprint

ESSO CSS Operation with Vertical Wells
Cold Lake, Alberta, Canada
(140,000 bbl/d)

Sources: Google Satellite Map
Sources: Energy Resources Conservation Board (ERCB) of Alberta
Surface Footprint

• Reduce surface footprint (further) with SAGD well pairs

Suncor Firebag SAGD Operation with Horizontal Well-Pairs, Athabasca, Alberta, Canada (35,000 bbl/day/Stage)
Greenhouse Gas Emission

• GHG emission from steam generation at 250° C
  – Burning natural gas (CO₂ emission = 0.532 tonne/Mscf)

![Bar graph showing CO₂ emission (kg) / Oil Recovery (bbl) vs Steam-Oil Ratio (SOR).]

- CSS & Steamflooding
- SAGD

Environmental Canada Data

Reduced GHG Emission

Improved SOR
Water Usage and Disposal

- Water usage for steam generation

![Graph showing water usage and steam-oil ratio (SOR)]

- CSS & Steamflooding
- SAGD

- Water Usage (bbl)
- Oil Recovery (bbl)

- Reduced Water Usage
- Improved SOR
Concept for New Technology

- **Steam-only**
  - Heat transfer controlled
  - High oil rate
  - High energy and water requirements
  - Commercial applications

- **Solvent-only**
  - Diffusion/dispersion controlled
  - Low oil rate
  - Low energy and water requirements
  - Field pilot stage

Methods to Reduce Viscosity:
- Heating
  - Fast
  - Steam-only
    - Heat transfer controlled
    - High oil rate
    - High energy and water requirements
    - Commercial applications
  - Hybrid
    - Steam + Solvent
  - Slow
    - Solvent dilution
      - Diffusion/dispersion controlled
      - Low oil rate
      - Low energy and water requirements
      - Field pilot stage

**Athabasca Bitumen Viscosity**

**Solvent dilution effect**

Viscosity (cP) vs. Temperature (°C)

Courtesy of Alberta Research Council (ARC)
Hybrid Steam-Solvent Processes

- Synergize advantages of steam and solvent processes
- Enhance oil rates and lower SOR
- Reduce environmental impact

Co-inject small amount of solvent with steam
Technology Development

Hybrid Steam-Solvent Processes

Laboratory Studies
- Proof of concept
- Property measurements
- Scale-up

Workflow

Numerical Modelling
- Model validation
- Mechanistic Analysis
- Field-scale prediction

Field Application
- Pilot tests
- Commercial Operation
Hybrid Steam-Solvent Processes

- **Nomenclature**
  - Expanding Solvent-SAGD (ES-SAGD)
  - Solvent Aided-Process (SAP)
  - Liquid Addition to Steam for Enhancing Recovery (LASER)
  - Many more ….

- **Different strategies:**
  - Solvent selection
  - Steam - solvent ratio
  - Continuous or cyclic
Laboratory Studies

Solvent Selection

- Hexane and diluents (a solvent mixture)
  - Evaporation temperatures closest to steam temperature
  - Steam-solvent ratio = 64 (by vol.)

“1-D” ES-SAGD Experiments

Laboratory Studies

Proof of Concept

- ES-SAGD versus steam-only
- Continuous diluents co-injected with steam
  - Steam-solvent ratio = 6.9 (by vol.)

"2-D" Scale-Model Experiments

Courtesy of Alberta Research Council (ARC), Canada

Numerical Modeling

Model Validation

- History match of 2-D scale-model experiments

**Temperature Profile @ 240 minutes**

- Oil Production Rate
  - Lab Test
  - Simulation

- Solvent Production Rate (85% Recovery)
  - Lab Test
  - Simulation

Numerical Modeling
Mechanistic Analysis

- Understand ES-SAGD process mechanisms
  - Solvent appears along slope of steam chamber
  - Observation not available from experiments

Profile @ 240 minutes

Numerical Modeling
Mechanistic Analysis

Temperature Profile @ 240 minutes

- Understand ES-SAGD process mechanisms
  - Solvent further reduces oil viscosity along the slope of steam chamber

Numerical Modeling
Field-Scale Prediction

• A bitumen asset in Western Canada
  – Preheat: 100 days; SAGD: 150 days
  – ES-SAGD: after 250 days
  – Solvent composition: 98% C₄ & 2% C₁

Numerical Modeling
Field-Scale Prediction

Oil Production and Steam Injection

- Improve oil production with solvent
- Reduce steam injection with solvent

Numerical Modeling
Field-Scale Prediction

In-Situ Upgrading

- The presence of solvent in produced oil improves its API
  - API is calculated based on composition of produced oil

Numerical Modeling
Field-Scale Prediction

Gas Saturation Distribution

Steam Chamber with SAGD Base Case

Steam Chamber with 5% Solvent Injection

- Solvent slows vertical growth of steam chamber (reduces heat loss) and allows it to grow more laterally

Challenges from Lab to Field

Optimal Solvent Injection Strategy

Continuous solvent injection

- Constant Rate
- Ramp-Up
- Ramp-Down

Cyclic solvent injection

- Constant Rate
- Ramp-Up
- Ramp-Down

- Unrealistic to test all strategies in the field
- Lab experiments and numerical studies can be useful
Challenges from Lab to Field
Optimal Amount of Solvent

- Not enough solvent
  - Less solvent dissolution in oleic phase
  - Less oil viscosity reduction

- Too much solvent
  - Excessive solvent in gaseous phase that forms an insulation blanket near steam chamber interface
  - Hinder propagation of steam front

SAGD Steam Chamber Interface

Not Enough Solvent
- Excessive solvent in gaseous phase that forms an insulation blanket near steam chamber interface
- Hinder propagation of steam front

Optimal Amount of Solvent
- Insulation Blanket

Too Much Solvent
- Solvent

SAP: Gupta, et al., SPE 137543 (2010)
Challenges from Lab to Field
Optimal Amount of Solvent

- Optimal amount of solvent varies throughout lifetime of process

SAP: Gupta, et al., SPE 137543 (2010)
Field Pilot Tests in Canada

Hybrid Process Field Pilots:
- Suncor / CNRL Burnt Lake – ES-SAGD
- Suncor Firebag – ES-SAGD
- Nexen Long Lake – ES-SAGD
- EnCana Senlac – SAP
- EnCana Christina Lake – SAP
- Imperial Oil Cold Lake – LASER

Map showing locations in Alberta and Saskatchewan with key cities and deposits.
Field Pilot Test
EnCana Senlac (January 2002)

- One well pair already in SAGD operation
  - Achieved peak rate
- Butane ($C_4$) was used as solvent

Oil Production Rate (bbl/d)

SOR and Energy Intensity (EI)

Field Pilot Test
EnCana Christina Lake (April 2004)

- One well pair already in SAGD operation
  - Achieved peak rate (after two years)
  - Worst performance in 4 side-by-side well pairs
- Butane (C_4) was used as solvent

Oil Production Rate (tonne/d)

Field Pilot Test Performance

EnCana Senlac & Christina Lake

• Very encouraging pilot results
  – Improved initial oil rate over 50% in Senlac and 150% in Christina Lake
  – Reduced SOR
  – Improved API° gravity of produced oil over a range of 0.7° - 1°

• Economic improvement – Senlac


• Cenovus (previously EnCana) is planning SAP commercialization near Christina Lake
Field Pilot Test
Imperial Oil Cold Lake (March 2002)

- One CSS pad chosen from two adjacent identically performed pads considered
  - Cycle 6 – CSS; Cycle 7 - LASER
- Diluent ($C_{5+}$ condensate) was used as solvent

Oil Production Rate ($m^3/d$) & Cumulative

Field Pilot Test Performance
Imperial Oil Cold Lake

• Very encouraging first LASER cycle (cycle 7) results
  – Recovered 80% of injected diluent
  – OSR declined for CSS pad but increased for LASER pad
  – Achieved an incremental “oil-to-solvent storage ratio*” of 10

* m$^3$ oil produced / m$^3$ solvent retained in reservoir

LASER: Leaute and Carey, CIPC (2005)
LASER Commercialization
Imperial Oil Cold Lake

- 10 pads
- Diluent injection (Q3 2007 – April 2009) in 10 pads
- Production is expected to reach peak rate in late 2010 to early 2011

LASER: Energy Resources Conservation Board (ERCB) of Alberta (2010)
Hybrid Steam-Solvent Processes
Reduction of Environmental Impacts

- Reduce surface footprint
  - Use horizontal wells (e.g., SAGD)

- Reduce GHG and water usage
  - Reduce SOR by 1 in a 100,000 bbl/day project
    - Reduce ~1 million tonnes/year of CO₂ emission
    - Reduce 100,000 bbl/day of water usage for steam generation

- Reduce water disposal
  - Recycle significant amount of produced water
Conclusions

• Hybrid steam-solvent process is a feasible heavy oil recovery technology
  – Concept proven - lab and numerical results
  – Technically successful field pilot tests

• Hybrid steam-solvent processes can:
  – Improved oil rate and SOR
  – Reduce environmental impacts
  – Improve quality of produced oil

There is continuous improvement on heavy oil recovery technologies to meet the challenges of environmental issues