Geosciences, Geomechanics, and New Heavy Oil Production Technologies

Maurice B. Dusseault
Massive stress changes occur
- Casing shear, massive sanding, properties change
- Some of these can have beneficial effects…
- Some are solely negative (casing shear)…
- Beneficial effects large in heavy oil production!
- Understanding these effects will…
  - Improve project design
  - Improve recovery factors (process sequencing)
  - Reduce operating costs
Oil Source of the Future

- Heavy and viscous oils will become the major oil source by 2040
- New technologies from Canada have succeeded in helping access this resource
  - SAGD, IGI
  - CHOPS, PPT
  - Others emerging…
- Geosciences!!
- Geomechanics!!

Source: Syncrude Canada
New Technologies…

- SAGD (Steam-Assisted Gravity Drainage)
- CHOPS (Cold Heavy Oil Prod. with Sand)
- PPT (Pressure Pulsing Technology)
- VAPEX (Vapor-Assisted Petr. Extraction)
- THAI™ (Toe-to-Heel Air Injection)
- HCS (Horizontal Cyclic Steam)
- Hybrids of these will be used in the future
- Projects will use them in 2 or 3 “phases”
The only viable commercial technology in 1985 for *in situ* highly viscous oil extraction from high porosity sandstones was CSS – Cyclic Steam Stimulation.
Currently, viable technologies at a commercial scale are expected in all categories (actual and emerging). But, many of these have huge geomechanics effects: first order effects that must be included in assessments.

### Technology Status - 2009

<table>
<thead>
<tr>
<th>Horizontal wells</th>
<th>SAGD</th>
<th>Cold Flow +PPT</th>
<th>Bold ones are commercialized</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HCS</td>
<td>VAPEX IGI…</td>
<td></td>
</tr>
<tr>
<td>THAI™</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical wells</td>
<td>Cyclic Steam Stimulation</td>
<td>CHOPS, PPT Cyclic solvent</td>
<td></td>
</tr>
<tr>
<td>Thermal</td>
<td>Non-thermal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Heavy Oil Production…

Production Processes

Primary
- Cold Production
  - CHOPS

Thermal
- Steam
  - CSS
  - Flooding
  - SAGD
- Combustion
  - Fire Flooding
    - THAI
    - Top Down

Non-Thermal
- Water Flooding
  - CO₂, Gas Injec.
  - Chemical Injec.
    - VAPEX

Hybrid Processes

Sequencing
Viscosity - Temperature

- Viscosity - Centipoises
- Oil Temperature °F
- Reservoir Temperature

- Wabasca
- Athabasca
- Cat Canyon
- Peace River
- Midway Sunset
- Cold Lake
- Kern River
- Bellevue
- Lloydminster
- La Hocha

Courtesy Bill Huang, ChevronTexaco
Inert Gas Injection

gas rates are controlled to avoid gas (or water) coning

horizontal wells parallel to structure

inert gas injection

mainly gas

three-phase zone

oil bank, two-phase zone

water-wet sand

water, one phase

keep $\Delta p$ to a minimum

$\Delta p$ (happy)

$\Delta p$ (sad)
SAGD Schematic

Courtesy Neil Edmunds, EnCana
SAGD and VAPEX

Keep $\Delta p$ small to maximize stability

overburden

“insulated” region

countercurrent flow

steam + oil + water + CH$_4$

liquid level

$\theta$

countercurrent flow

lateral steam chamber extension

CH$_4$ + oil

oil and water

water leg

cool bitumen plug

Keep $\Delta p$ small to maximize stability
Shale Barriers and SAGD

Shales are impermeable to steam, and behave differently than sands.

SAGD passes through thin shales ($\Delta V/\Delta T$ & t effects).

Shales 1 m thick can be passed: thermal geomechanics effects.
CHOPS

- C – Cold
- H – Heavy
- O – Oil
- P – Production with Sand
- Produces > 30% of Cdn <20°API production
- Major OPEX reductions in 1990’s
- 10-20% OOIP recovery in good reservoirs
- Applicable worldwide if reservoir conditions are suitable (unconsolidated sand)
Well 14-8 Performance

Luseland Field

Central Well 14 - 8

Start CHOPS

Oil rate

Water rate

Production rate (bbl/d)

Jan-81 Jan-85 Jan-89 Jan-93 Jan-97 Jan-01

Jan-81 Jan-85 Jan-89 Jan-93 Jan-97 Jan-01
Short Flow Path Development

Short flow path in low $k_v$ area, long flow path in high $k_h$ zone

Massive sand yield is the mechanism behind CHOPS
Edam Field – 31 Wells

Production rate, oil or water – m$^3$/d

- 1979 - 2003

- Oil - m$^3$/day

- Water - m$^3$/day
Edam Field – Sand!

More sand in the well drilling period

Cumulative oil or water production – m³

Cumulative sand production – m³

NOTE: Sand curve is from 13 wells only of the 31 wells included in the sample
CHOPS Produced Sand in Canada

Heavy Oil is a “Dirty” Business
CHOPS Mechanisms

Overlying strata flex downward, an effective form of gravity drive

Oil, gas, sand and water produced as a slurry

Coal seam

Remolded and wormholed zone

Solution gas pressure and foamy oil behavior

Moving sand means no fines or asphaltene blockage

Remote water influx

Highly complex!
Why Increased Oil Production?

- Sand flux increases fluid flux
- Dilation and sand production increases the permeability in a growing zone
- Foamy oil mechanics aid production and also maintain sand flux
- If sand is produced – no skin development
- The overburden weight helps shear and dilate sand, driving it toward the wellbore

The “toothpaste” tube effect…

Extrusion of yielded sand
Oil-Wet - Waterflood

<table>
<thead>
<tr>
<th>No pulsing</th>
<th>Pulsing</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Time = 139.2 s</strong></td>
<td><strong>Time = 138.7 s</strong></td>
</tr>
</tbody>
</table>

35 cP light oil water flood
0.5 m static pressure head
identical tests

Pulsing increases oil rates!
The THAI™ Process

Air or O₂ (±H₂O)

Horizontal well enforces a short flow and reaction zone, traditional instabilities are greatly reduced

Combustion zone

Mobile gas and oil bank

Cold reservoir

Product

toe

heel

The Whitesands Project looks very promising (15 months...
Geomechanics in CSS

- CSS = high pressures, high temperatures
  → Fracturing, massive $\Delta \sigma$, shearing
- Beneficial effects on rock properties...
  → Porosity and permeability increases - dilation
  → Breaching shale beds and flow barriers
  → Fracture orientation changes: better contact
- The reservoir is improved for SAGD
- Negative? Casing shear, seal impairment
Shell Peace River HCS

HCS: Horizontal Cyclic Steam stimulation
In CSS, pressure response changes with cycle number

- Stress effects +
- Steam effects +
- Geometry effects

Reduced $p_F$

Increased $p_F$

$\sim 0.3 - 0.4 \cdot \sigma_v$

original $\sigma_v (= \gamma \cdot z)$
Recompaction Drive Proof

Vertical heave – Δz - m

1.00 0.75 0.50 0.25

Full recom- paction drive

Δz

injection soak production

initial ground elevation

1 2 3 4
Ground Surface Movements

CSS – IOL Cold Lake

Uplift
Subsidence

mod. Stancliffe & van der Kooij, AAPG 2001
Shell Oil Canada – Peace River

Surface uplift & tilt data

reservoir inversion grid with 50x50m grid cells

ref. Nickle’s New Technology Magazine, Jan-Feb 2005
Casing Shear

Reality

Simulation
Mixed Development

- CHOPS wells
- PPT wells
- Horizontal wells
- Other sands
- Continuous sands
- Water sand
## The New Technologies

<table>
<thead>
<tr>
<th>Method</th>
<th>Years</th>
<th>Status (2009)</th>
<th>Suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHOPS</td>
<td>&gt;15</td>
<td>$$$ - fully commercial</td>
<td>Best for 5-20 m zones, no mobile water or water legs</td>
</tr>
<tr>
<td>SAGD</td>
<td>~6</td>
<td>$ profitable</td>
<td>Probably limited to thicker zones, &gt; 15-20 m</td>
</tr>
<tr>
<td>PPT</td>
<td>2(?)</td>
<td>$$ early days</td>
<td>Useful along with other methods (cold flow, CHOPS)</td>
</tr>
<tr>
<td>VAPEX</td>
<td>?</td>
<td>some field trials</td>
<td>Best in &gt;20°API cases, or along with SAGD</td>
</tr>
<tr>
<td>IGI</td>
<td>&gt;15</td>
<td>$$$</td>
<td>Good $k_v$ &amp; low $\mu$ needed</td>
</tr>
<tr>
<td>HCS</td>
<td>4</td>
<td>$</td>
<td>Lower $k$ than SAGD, &gt;15m</td>
</tr>
</tbody>
</table>
Conclusions

- Conventional oil will peak soon
- Good for heavy oil, IOR, profits
- Remarkable technology advances recently
- New ideas for light oil as well
- **We must try to consolidate & perfect them**
- The role of geosciences and geomechanics is fundamental in technology choice, sequencing
- Geomechanics is becoming a mainstream discipline, vital to manage heavy oil value
The Next Challenge…

- Naturally Fractured Carbonates!
- ~2 Tb of heavy oil, 15% of world OOIP
- Multi-porosity systems
  - Fractures
  - Matrix
  - Vugs (dolomitization)
- We need to develop new production technologies for HO in NFCR’s
- A geoscience and geomechanics challenge.
Different Joint Sets

Source: N. Barton and A. Makurat
The Next Challenge…
Rough or Smooth?

Source: N. Barton and A. Makurat