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Applying High Pressure Air Injection to Recover Deep, Heavy Oil With In-Situ Combustion

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Outline

- World’s Heavy Oil Resources
  - Where they are
  - Why not use steam?

- What is High Pressure Air Injection?
  - Projects
  - Operations
  - Mechanisms

- Deep Heavy Oil Projects
  - Lessons from Simulations
  - Field projects – India, California, Colombia

- Alternatives – DHSG and Gas-Water

- Summary


## World Heavy Oil Resources

Source: USGS Heavy Oil Strategic Resource 2003

<table>
<thead>
<tr>
<th>Region</th>
<th>Technically Recoverable BBO</th>
<th>OIP BBO</th>
<th>Recovery Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>566.2</td>
<td>1,845</td>
<td>30.7%</td>
</tr>
<tr>
<td>South America</td>
<td>265.8</td>
<td>2,045</td>
<td>13.0%</td>
</tr>
<tr>
<td>Africa</td>
<td>50.2</td>
<td>470</td>
<td>10.7%</td>
</tr>
<tr>
<td>Europe</td>
<td>5.1</td>
<td>34</td>
<td>15.0%</td>
</tr>
<tr>
<td>Asia</td>
<td>197.7</td>
<td>1,493</td>
<td>13.2%</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>1,085</strong></td>
<td><strong>5,887</strong></td>
<td><strong>18.4%</strong></td>
</tr>
</tbody>
</table>

- North American recovery high – thermal used
- Rest mostly cold production

Imagine if recovery was 40% everywhere
Locations of Deep Heavy Oil Resources

Alaska, California, China and Russia have most of the rest

Arabia and Latin America have 70% of Deep Heavy Oil
Most of Heavy Oil is Too Deep for Steam

Steam Quality Decreases with Depth

- Use HPAI where steam quality less than 50%.
- Use HPAI to improve thermal efficiency
What is **High Pressure Air Injection?**

- HPAI proven EOR Technique for Light Oils
- Maintains Pressure and Oil Production

**Requirements**
- Must be Good Gas-Injection Candidate
  - Viscous Dominated
  - Dipping and Gravity Dominated
- Hot Enough to Consume \( \text{O}_2 \)

- High pressure increases gas solubility and oxidation

**High Pressure Prevents Oxygen Production**
How Does This Affect Heavy Oil Projects?

- High pressure in heavy-oil projects limits gas production
- **High Pressure Air Injection** produces flue gas and reduces viscosity by
  - higher gas solubility at high pressure
  - and an engineered steam bank

![Diagram showing temperature, viscosity, and gas-oil ratio over time in different zones of an oil project.](chart.png)
Why Inject Air Into Oil Reservoirs?

- HPAI is just another gas injection process
- Examples: reservoir gas, rich gas, CO$_2$, N$_2$.
- Air used for Light Oil if CO$_2$ unavailable
- Safely used for 40 years
- Best Documented
  - West Heidelberg, Mississippi
  - Buffalo Red River Carbonates

Operate as a high-pressure gas injection project
Williston Basin HPAI Projects

Reservoirs hot, low-perm carbonates with light oil

Cedar Creek Anticline 2000

Buffalo
Air injection - 1979
Spread to most of Red River carbonates

Cedar Hills Carbonate 2002

Cedar Hills - Horizontal Wells One Mile Apart
Projected Gross Oil under Primary and Secondary

Production reaches Primary Rate in 2 Years
Operations and Safety

40 Years of Safe Operations - *Lessons Learned:*

- Use turbine-reciprocating compressors
- Use synthetic lubricant
- Use large inter stage coolers (steam clean twice/year)
- No low spots where oil or water accumulates

Compressors at Cedar Hills
Injector Design

- Must prevent $O_2$ in Casing
- Use Permanent hydraulic packer
- Premium tubing connections
- Test at High Pressure
- Use positive pressure on casing for leak detection.
Now Consider Heavy-Oil Recovery  

*Big Effect of Gas on Viscosity*

- **Purpose** - reduce viscosity 90 to 99%
- **Increase both** GOR and temperature
- **Dissolved gas can reduce viscosity** 90%
- **This accelerates oil production**
Effect of Gas on Steam

- Gas reduces the partial pressure of steam
- Accelerates evaporation and delays condensation
- Steam condenses deep in reservoir
- This improves heat transfer
- And accelerates oil production
Importance of Steam Generation

- Steam bank makes process stable and safe.
- Generate steam from combustion and evaporation
- Bottom water or co-injected water good
Oil Combustion – ARC Results

- Steam or hot water ensure combustion
- Bottom water, aquifers Good

- Rate = f(T)*[O₂ partial pressure]
- High Pressure Increases Rate

When Temperature > 100°C, ignition occurs within a few days
Energy Released Increases Pressure

- Retain heat of combustion in thick reservoir
- Heat converted to increased pressure
API Gravity Increase

- Pyrolysis can result in higher API gravity

- Important chemical reactions
  1) Oxidation - Oil + O$_2$ $\rightarrow$ CO$_2$ + H$_2$O + energy
  2) Pyrolysis - Heavy Oil $\rightarrow$ Light Oil + C(coke)
Depth 1000 meters, pay 5 meters, 70°C, 100 kg/cm²

Monocline; dipping 3 to 5°, 8 Darcy, porosity 28-30%, viscosity 150 to 1000 cp.

Water encroaches in high perm zone in sand

Advantages of Crestal Edge Drive

- Easy to control
- Gravity helps nullify heterogeneity
- Flue gas remains in gas cap
- Producers are only heated once and
- Can become injectors
Balol Structure and Production

New Injectors Being Drilled to Increase Production and reach 1.49 MMt Cum Oil
Water cut drops from 80% to 60%
Expected decrease in oil recovery
Injection Decreased in 2008
Air Injection Begins
Injected Air
Pleito Creek California – Wet Oxygen Injection

- Oxygen and water are injected at the top of the reservoir
- Oil oxidized to CO₂ and heat which makes steam
- Mobilized oil drains to the horizontal wells
STAR Project – Colombia
(Syncronized Thermal Additional Recovery)

- 12.3 API, 800 meters deep
  - bottom water reservoir
  - inject air for combustion
  - inject water for steam

- Expected to increase recovery 10 - 40%
Toe to Heel Air Injection (THAI™) – Process

- Vertical injector horizontal producer
- Inject air at toe
- Oil drains to horizontal well
- Liquid prevents Gas bypass

- Advantage versus SAGD
  - thermal efficiency, less equipment
  - more oil, some upgrading
THAI™ – Whitesands Pilot

- 3 injector-3 producer project began in 2006
- Injected steam for 3 months then air
- Average 67 m³/d oil, 60 m³/d water – AOR 1,400
- Produced gas generates power – no external energy
- Oil upgraded from 7.9 to 12.3 API
- Estimated to produce 17% more oil than SAGD
Down Hole Steam Generator – Operation (DHSG)

- DHSG can operate like HPAI
- Reduce flame temperature with excess gas
- Excess O\textsubscript{2} prevents coke in burner
- Excess O\textsubscript{2} burns residual oil - forms steam
- Best combination - CO\textsubscript{2} and O\textsubscript{2}
DHSG Results

- Fast moving, warm CO₂ lowers oil viscosity 99%
- Accelerates production before combustion front
- Keep pressure high – promote gas solubility
Production with DHSG

- CO₂ increases oil production with steam
- Excess O₂ in DHSG exhaust accelerates production
Alternative Technology

- Gas/water coinjection works well if oil is not too viscous

Published Example of CO$_2$ on oil viscosity

**CO$_2$-Enhanced Waterflooding?**

Now piloting in Saskatchewan
Target Reservoirs

- Most heavy-oil fields are too deep for steam; many only produce 10% of oil

- Best targets will be
  1) Between 750 and 3,000 meters
  2) Low GOR
  3) Pressure not depleted yet
  4) Bottom water or edge aquifer

- Use edge drives or horizontal wells not patterns
  - Maintain pressure by flowing wells
  - Consider THAI™

- Consult with Canadian experts, UC, AI, SRC

- 70 percent recovery in swept zone possible; less energy needed
Conclusions

- HPA or GI can increase deep, heavy-oil recovery
- Use HPAI or GI techniques with water coinjection, so
  1) Gas reduces the oil’s viscosity
  2) Steam bank makes $O_2$ front stable
  3) Gas makes steam condense later
  4) High temperatures can upgrade oil in situ
- These accelerate and increase production
- Knowing how to manage high pressure gas injection can unlock heavy oil reserves.

Double world’s heavy oil production?
Thank You!
Спасибо!
谢谢！！