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Meeting the Challenge of Marginal Oil Reservoirs: Oil Recovery in Saskatchewan

B.J. Kristoff
Outline

◆ Background
◆ Technology vs. Marginal Reservoirs
  – Horizontal Wells
  – Cold Production
  – CO₂ EOR
◆ Future Challenges
Saskatchewan Quick Facts

- 2nd largest oil producing province
- 3rd largest gas producing province
- Abundant coal reserves
- Wind, hydro, biomass
- “Saudi Arabia” of Uranium
Technology to Meet the Challenge of Saskatchewan Oil Reservoirs
“If at first the idea is not absurd, then there is no hope for it”

Albert Einstein
Horizontal Wells

◆ 1st Saskatchewan horizontal well drilled in 1987 in the Tangleflags N. Lloydminster Sand

◆ 6th horizontal well in Canada
Tangleflags N.
Lloydminster Sand

- On production since 1977
- Good (5%) primary in non-bottomwater area
- Poor (0.5%) primary recovery due to water coning
<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>450m (1475 ft)</td>
</tr>
<tr>
<td>Gross Zone Thickness</td>
<td>35 m (115 ft)</td>
</tr>
<tr>
<td>Oil Zone Thickness</td>
<td>27 m (89 ft)</td>
</tr>
<tr>
<td>Porosity</td>
<td>33%</td>
</tr>
<tr>
<td>Oil Saturation</td>
<td>80%</td>
</tr>
<tr>
<td>Permeability</td>
<td>4 Darcies</td>
</tr>
<tr>
<td>Initial Temperature</td>
<td>19°C (66°F)</td>
</tr>
<tr>
<td>Initial Pressure</td>
<td>4076 kPag (591 psig)</td>
</tr>
<tr>
<td>Stock Tank Oil Density</td>
<td>978.9 kg/m³ (13.1°API)</td>
</tr>
<tr>
<td>Oil Viscosity @ 19°C - Dead</td>
<td>13,000 mPa.s</td>
</tr>
<tr>
<td></td>
<td>4,000 mPa.s</td>
</tr>
<tr>
<td></td>
<td>Live</td>
</tr>
</tbody>
</table>
Tangleflags N. Steamflood Project Area Primary Well Performance and Recovery Status

<table>
<thead>
<tr>
<th>Well</th>
<th>Date of First Production</th>
<th>Cum. Oil Prod. To Dec. 31/90 (m³)</th>
<th>Recovery to Dec. 31/90 (% OOIP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D2-23</td>
<td>86/08</td>
<td>3737.8</td>
<td>0.75</td>
</tr>
<tr>
<td>A7-23</td>
<td>85/10</td>
<td>70.1</td>
<td>0.01</td>
</tr>
<tr>
<td>A9-23</td>
<td>84/08</td>
<td>972.7</td>
<td>0.19</td>
</tr>
<tr>
<td>C9-23</td>
<td>85/07</td>
<td>1065.0</td>
<td></td>
</tr>
<tr>
<td>A10-23</td>
<td>86/12</td>
<td>8218.3</td>
<td>1.52</td>
</tr>
<tr>
<td>D10-23</td>
<td>82/01</td>
<td>5749.4</td>
<td></td>
</tr>
<tr>
<td>A15-23</td>
<td>82/12</td>
<td>2090.6</td>
<td>0.26</td>
</tr>
<tr>
<td>A15A-23</td>
<td>84/08</td>
<td>469.2</td>
<td></td>
</tr>
<tr>
<td>A16-23</td>
<td>84/08</td>
<td>8958.1</td>
<td>1.04</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>31,531</td>
<td>0.62</td>
</tr>
</tbody>
</table>
Tangleflags North Steamflood Well Locations
Tangleflags N. Horizontal Well Steam Project

- 1st Saskatchewan horizontal well
- At its peak produced 1% of Saskatchewan production
- Currently still producing at 380 b/d
- Recovered 3.2 million bbls (107 % OOIP)
Horizontal Well Applications in Active Bottomwater Reservoirs
Winter Cummings Sand Pool

- Discovered in 1979
- By 1985 – 12 vertical producers
- Only 3 wells had cumulative production exceeding 1500 cubic metres
- Typical recoveries < 0.5% OOIP
- 120 million barrels in place – no economic recovery
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>650m (2130 ft)</td>
</tr>
<tr>
<td>Oil Zone Thickness</td>
<td>14 m (46 ft)</td>
</tr>
<tr>
<td>Bottomwater Thickness</td>
<td>16 m (52 ft)</td>
</tr>
<tr>
<td>Porosity</td>
<td>30%</td>
</tr>
<tr>
<td>Oil Saturation</td>
<td>82%</td>
</tr>
<tr>
<td>Permeability</td>
<td>6 Darcies</td>
</tr>
<tr>
<td>Initial Temperature</td>
<td>28°C (82°F)</td>
</tr>
<tr>
<td>Initial Pressure</td>
<td>5910 kPag (857 psig)</td>
</tr>
<tr>
<td>Stock Tank Oil Density</td>
<td>971 kg/m³ (14.2°API)</td>
</tr>
<tr>
<td>Oil Viscosity @ 28°C - Live</td>
<td>3,000 mPa.s</td>
</tr>
</tbody>
</table>
Schematic of watercresting in a horizontal well
Winter Cummings Sand Pool

Horizontal Well Development

- First horizontal wells drilled in 1988
- Development continued with 1200m long horizontals at 150m spacing
- In-fill wells at 75m
- Over 90 h-wells producing 1000 m$^3$/day
- 6-11% recovery at 95-98% watercut
Horizontal Well Applications in Light/Medium Oil Reservoirs
Weyburn Unit
Southeast Saskatchewan

- Discovered in 1955
- 70 square mile – 1.1 billion bbls OOIP
- Waterflood in 1964
- Infill vertical development in 1985
- Horizontal Well Development in 1991
A typical horizontal well initially produces at 150 - 200 bbls/d and recovers 150,000 - 200,000 bbls.

A typical vertical well initially produces at 40 - 60 bbls/d and recovers 50,000 - 70,000 bbls.
Horizontal Well Productivity

Producing Oil Wells
December 2004 - SE Saskatchewan

- Vertical Wells: 5,099 or 62%
- Horizontal Wells: 3,190 or 38%

Monthly Oil Production
December 2004 - SE Saskatchewan

- Horizontal Wells: 513,000 m³ (3.23 MMbbls) 69%
- Vertical Wells: 226,000 m³ (1.42 MMbbls) 31%
Number of Horizontal Wells Drilled Per Annum in Alberta and Saskatchewan

- **Saskatchewan**
- **Alberta**

![Bar chart showing the number of horizontal wells drilled per annum in Alberta and Saskatchewan from 1987 to 2000.](chart.png)
Horizontal Wells

- Applied to virtually all reservoir types
- Used in primary, water flood and EOR
- Test ground for development of multi-laterals
- Responsible for doubling Sask. production from early 90’s until now
Cold Production

- Viable with progressive cavity pumps
- Requires foamy oil and sand production
Plover Lake West Bakken Pool

- Discovered in 1974
- Steam project with horizontal wells – plagued with high sand production
- 57 producers, 40 shut-in, 24 suspended wells – cold production
<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>812m (2664 ft)</td>
</tr>
<tr>
<td>Oil Zone Thickness</td>
<td>8 m (26 ft)</td>
</tr>
<tr>
<td>Porosity</td>
<td>30%</td>
</tr>
<tr>
<td>Oil Saturation</td>
<td>70%</td>
</tr>
<tr>
<td>Permeability</td>
<td>1.5-4 Darcies</td>
</tr>
<tr>
<td>Initial Temperature</td>
<td>27°C (66°F)</td>
</tr>
<tr>
<td>Initial Reservoir Pressure</td>
<td>6400 kPa (930 psi)</td>
</tr>
<tr>
<td>Current Reservoir Pressure</td>
<td>1100 kPa (160 psi)</td>
</tr>
<tr>
<td>Stock Tank Oil Density</td>
<td>978.9 kg/m³ (12°API)</td>
</tr>
<tr>
<td>Oil Viscosity @ 19°C - Dead</td>
<td>2,500-7,000 mPa.s</td>
</tr>
<tr>
<td>- Live</td>
<td>1,000-1,400 mPa.s</td>
</tr>
<tr>
<td>Solution Gas Oil Ratio</td>
<td>16.6 m³/m³ (93Scf/Stb)</td>
</tr>
</tbody>
</table>
Plover Lake West Bakken Pool Cold Production

- 6-9 well produced 70,000 m³
- Pre-Cold Production rate of 4-8 m³/day
- Cold Production rate of 20-40 m³/day
- Pilot area recovery of 350,000 m³ or 15.1% of OOIP
Cold Production

- Viable due to advent of progressive cavity pumps
- Requires formation and flow of foamy oil along with sand production
- Approximately 3700 wells produce 137,000 b/d in Lloydminster area
CO$_2$ Enhanced Oil Recovery
Weyburn Unit
Southeast Saskatchewan

- Discovered in 1955
- 70 square mile – 1.1 billion bbls OOIP
- Waterflood in 1964
- Infill vertical development in 1985
- Horizontal Well Development in 1991
- Phase 1A CO₂ Flood in 2000
## Weyburn Unit: Reservoir Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formation Depth</td>
<td>1400 mKB</td>
</tr>
<tr>
<td>Original Reservoir Pressure</td>
<td>15043 kPa</td>
</tr>
<tr>
<td>Reservoir Temperature</td>
<td>62°C</td>
</tr>
<tr>
<td>Reservoir Temperature</td>
<td>26%</td>
</tr>
<tr>
<td>Average Porosity (Marly)</td>
<td>11.2%</td>
</tr>
<tr>
<td>Average Porosity (Vuggy)</td>
<td>26%</td>
</tr>
<tr>
<td>Average Permeability (Marly)</td>
<td>9.4 md</td>
</tr>
<tr>
<td>Average Permeability (Vuggy)</td>
<td>5.6 md</td>
</tr>
<tr>
<td>Oil Gravity</td>
<td>28° API</td>
</tr>
<tr>
<td>Bubble Point Pressure</td>
<td>6661 kPa</td>
</tr>
<tr>
<td>Gas-oil Ratio at $P_b$</td>
<td>23.01 s m$^3$/m$^3$</td>
</tr>
<tr>
<td>Oil Viscosity at $P_b$</td>
<td>3.36 mPa·s</td>
</tr>
</tbody>
</table>
Weyburn Unit Oil Production

Date

BOPD (Gross)

Jan-55
Jan-58
Jan-61
Jan-64
Jan-67
Jan-70
Jan-73
Jan-76
Jan-79
Jan-82
Jan-85
Jan-88
Jan-91
Jan-94
Jan-97
Jan-00
Jan-03
Jan-06
Jan-09
Jan-12
Jan-15
Jan-18
Jan-21
Jan-24
Jan-27

Original Verticals
Infill Verticals
Hz Infill
CO2

Actual
Forecast
Weyburn Unit Phase 1

CO2 Injection Begins
Oct, 2000

Total Production (BOPD)

- Actual
- Base Waterflood

Jan-96 to Jan-04
Midale Unit
Southeast Saskatchewan

- Discovered in 1953, unitized in 1962
- 0.5 billion bbls OOIP
- Horizontal Wells and Waterflood Modifications in late 80’s early 90’s
- Cumulative production 130.0 mmstb or 25.3% OOIP
- Current production 6,755 bopd at 90% watercut
Midale Unit
Southeast Saskatchewan

- CO₂ Demonstration Project (1992-1999)
- CO₂ Flood expansion second half of 2005
Saskatchewan Oil Production – Future Challenges
WSCB Conventional Heavy Crude Oil Production*

![Graph showing WSCB Conventional Heavy Crude Oil Production from 1991 to 2025, with data for Saskatchewan and Alberta.](image-url)
The Future: Production Challenged Reservoirs

- Cold Produced Reservoirs
- Active Bottomwater Reservoirs
- Post Waterflood
The Future: Enhanced Oil Recovery

- Carbon Dioxide Injection
- Solvent Vapour Extraction
- Air Injection
- Enhanced Water Flood/Chemical Flooding
- Immiscible Gas Injection
- Modified Steam Injection
The Future:
Oil Price and Differentials

- US$50/bbl WTI
- Heavy Oil Differentials of CDN$27/bbl
- Upgrading?
Summary

- Wealth of marginal, challenged reservoirs.
- Saskatchewan: a “Technology Playground”
- Technologies are transferable
- Big players come to play
- Learn and share from past experience
Acknowledgment

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