REU Houston 2014
Enhanced Reserve and Resource Estimates in a “Big Data” World

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Introduction

• Geology and unconventional resources

• Unconventional resource and the evaluation cycle

• Production analysis and it’s related challenges

• Some simple flow regime diagnostics

• Decline Curve Analysis (DCA) -- some methods analyzed

• “Big Data” and DCA

• Some example plays....
Sample Oil Plays

Tight ("Halo") Oil Plays:

Cardium (sandstone)

West Central SK Viking (sandstone)

Source: Company data, Macquarie Research, April 2010
AB Cardium and WC SK Viking Oil Plays

<table>
<thead>
<tr>
<th></th>
<th>AB Cardium Oil</th>
<th>WCSK Viking Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Depth (ft)</td>
<td>4,000 - 7,500</td>
<td>2,100 - 2,500</td>
</tr>
<tr>
<td>API (deg)</td>
<td>35-45</td>
<td>32 to 38</td>
</tr>
<tr>
<td>Initial Pressure (psia)</td>
<td>1,500 - 3,500</td>
<td>800 - 1,000</td>
</tr>
<tr>
<td>Permeability (md)</td>
<td>0.1+</td>
<td>0.1+</td>
</tr>
<tr>
<td>Original Oil In Place/Section (MMstb)</td>
<td>1.0 - 15.0</td>
<td>4.0 - 12.0</td>
</tr>
</tbody>
</table>

410 miles+/-

Vt. Well extents

Alberta Saskatchewan

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Production History

Western Canadian Tight Oil and Halo Oil Plays
14737 Wells - Group By: VIK CARD HZ HALO OIL - CD Avg Oil (bbl/day)

- Viking
- Cardium
- Other Canadian Tight Oil

40%+/-
GOR Comparisons

GOR vs Time
5832 Wells - Group By: VIK CARD HZ HALO OIL - GOR (scf/bbl)

Calendar Days

GOR scf/bbl

Cardium HZ (2890)
Viking HZ (2942)
Geology Overview – AB Cardium

Conglomerate
Sandstone/Shale
Transitional/Bioturbated Zone

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WCSB Atlas
1. Finely laminated sand stained with oil (brown) and grey shale. The very fine laminations are beyond the resolution of most logging tools hence the logging response is an average of the sand and shale properties
2. A resistivity cut off and neutron response can identify gross interval. Neutron – density separation is indication of sand content
3. Identifying ‘sand pay’ is very difficult from logs
4. Core greatly helps to tie log character to what’s really happening in the subsurface
Unconventional Resource Evaluation Cycle

Estimated PIIP
- Log analysis and petrophysical interpretation
- Core

Undeveloped Reserves Assignments
- Assign reserves and resources offsetting performance using volumetrics (if reliable) and analogy
- Technological evolution considerations

Relatively High Uncertainty for the (unconventional)
Viking & Cardium oils

Production Analysis
- Flow regime identification
- Empirical methods/methods for transient flow periods
- Hyperbolic extrapolations in BDF period

Recovery Factors
- Check performance / decline analysis versus PIIP estimates
Challenges

...all these drills are in one section.
Challenges

Improving results with time...Effect of technology & learnings
Viking: Are IP Rates and EUR correlated?

Even at 365 days, IP Rate and EUR are only weakly correlated.
Viking IP to EUR Ratio – Variability!

Units: Bopd/MBbl

Legend:
First Month Rate/EUR Ratio
- 2.6+
- 2.4 to 2.6
- 2.2 to 2.4
- 2.1 to 2.2
- 1.9 to 2.1
- 1.7 to 1.9
- 1.5 to 1.7
- 1.3 to 1.5
- 0.6 to 1.3

Steeper decline profiles
Vertical wells in section 21-030-21W3
Flow Regime Diagnostics – Viking Example

HZ wells in section 21-030-21W3
Cardium HZ - Flow Regime Diagnostics (Auto-fitted)
Cardium HZ - Flow Regime Diagnostics (Auto-fitted)

1,003 HZ wells
Cardium HZ - Flow Regime Diagnostics (Auto-fitted)

Legend:
- Td eff (mo)
  - 26.2+
  - 25.2 to 26.2
  - 24.1 to 25.2
  - 23.2 to 24.1
  - 22.3 to 23.2
  - 21.5 to 22.3
  - 19.6 to 21.5
  - 17.5 to 19.6
  - 11.2 to 17.5

6 miles
Cardium HZ - Flow Regime Diagnostics (Auto-fitted)
Sample individual well “qDb” diagnostic

Noise in “b” – common with monthly data
PLE – Viking individual well example
DCA Models

• **Modified Arp’s Hyperbolic**
  
  **Pros:**
  
  Early-time regression stability, simplicity, industry “popularity”

  **Cons:**
  
  Can overestimate reserves if “b” and $D_{\text{min}}$ not selected carefully.

• **Stretched Exponential**
  
  **Pros:**
  
  Models transient flow well, good for quick regressions on large databases; Possible to calculate input parameters from cumulative production values.

  **Cons:**
  
  Parameter regressions on “tau” and “n” can be unrealistic/unstable in early time; BDF is not modeled in later time.
DCA Models

- **Power-Law Exponential**
  Pros:
  - Very flexible, can be “tuned” to model any flow regime; Consistent and stable results for tight oil
  Cons:
  - Parameter regressions can be unrealistic/unstable in early time if not constrained

- **Duong Model**
  Pros:
  - Quick regression capability, very good at modeling transient flow; Modified variants of Duong available to improve late life behaviour
  Cons:
  - Not great for tight oil; Tends to overpredict duration of transient flow behavior for tight oil, even using modified variants
DCA Models

- **Long Duration Linear Flow Model (aka Composite Arps)**
  
  **Pros:**
  
  Very flexible; Quick & stable regressions; Multiple segment model corresponds to actual physical flow regime behaviour
  
  **Cons:**
  
  Can be time-consuming to create forecast in commercial software
Sample Curve Fit – Viking Well
Sample Curve Fit – Viking Well

Rate vs. Time

@ 6 mo
Sample Curve Fit – Viking Well

Rate vs. Time

@ 18 mo
Sample Curve Fit – Viking Well

Rate vs. Time

@ 36 mo
Revision Trends - Cardium

Cardium HZ Oil - P50 Revision Trends by DCA Method
(128 wells fitted)

\[ \text{% overprediction} = \frac{\text{EUR\_prediction}}{\text{EUR\_Actual}} - 1 \]

- Arps Hyperbolic $b=0.6$ (Final 6 month segment only)
- Arps Hyperbolic - 3 Parameter Regression (Full Life Fit)
- Exponential (Full Life Fit)
- Arps Hyperbolic, $b=0.6$ (Full Life Fit)
- Stretched Exponential Method (Full Life Fit)
- Power Law Exponential Method (Full Life Fit)
- Duong Method, Modified with $q_{inf} = 0$, $D_{min} = 5\%$ (Full Life Fit)
- Long Duration Linear Flow Model @ $t_{bdf} = 2$ yr, $b_{bdf} = 0.6$ (Pre-BDF Fit Only)
- Arps Modified Hyperbolic @ $b=1.1$, $D_{min} = 5\%$
Revision Trends - Viking

WC Sask Viking HZ Oil - P50 Revision Trends by DCA Method
(107 wells fitted)

- Arps Hyperbolic (6 mo final segment only)
- Hyperbolic - 3 param-regression (Full Life Fit)
- Exponential (Full Life Fit)
- Arps Hyperbolic, b=0.6, (Full Life Fit)
- Stretched Exponential Method (Full Life Fit)
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Viking HZ OIL – Results of 107 wells best-fit

Power-Law Exponential Method
(Full Life)

% overprediction

P10 revision
P50 revision
P90 revision

= EUR_prediction / EUR_Actual -1

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Cardium HZ OIL – Results of 128 wells best-fit

Duong Method (Full Life)
Modified with $D_{\text{min}} = 5\%$ and $q_{\text{inf}} = 0$

% overprediction

<table>
<thead>
<tr>
<th>Months</th>
<th>6</th>
<th>12</th>
<th>18</th>
<th>24</th>
<th>30</th>
<th>36</th>
<th>42</th>
<th>48</th>
<th>54</th>
</tr>
</thead>
<tbody>
<tr>
<td>% overprediction</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
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<td>0%</td>
<td>0%</td>
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<td>0%</td>
</tr>
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</table>

-150% -100% -50% 0% 50% 100% 150%
Modified Arps – Viking Fit Detail

Viking HZ OIL – Results of 107 wells best-fit

Arps Modified Hyperbolic (Full Life)
\( (b = 1.1, D_{\text{min}} = 5\%) \)

% overprediction

-60% -40% -20% 0% 20% 40% 60% 80% 100% 120% 140%

6 12 18 24 30 36 42 48 54 months
Scaling up .... “Big Data”

EUR Histogram from a bootstrapping resampling method on final decline segment
A map such as this is can help shape the boundaries between type curve regions.

Based on PLE EUR Estimates – 2007 to 2014 Rig Release
Conclusions

• Multiple type curves are required to adequately forecast development cases

• The wide range of predicted EUR fitted for wells with less than 1-3 years of production data suggests that use of analogies should be combined with DCA estimates for immature wells

• Transient flow within most horizontal wells in the Cardium and Viking is relatively brief, ranging from 1 to 3 years on most wells. Some Viking wells may never show a stabilized “b” parameter

• During transient flow periods within the tight oil plays analyzed, fitting with multiple different DCA methods simultaneously may help in gaining perspective on the range of potential outcomes
Thank You

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