Using well log analysis to identify residual oil zones at Noble and Kenner West Oil Fields, Illinois

Nathan P. Grigsby Nathan D. Webb, and Scott M. Frailey
Outline

• Motivation
• Ideal Saturation Curve
• Method
• Noble Field
• Kenner Field
• Conclusions
Motivation: ROZs+CO$_2$EOR

• Thick naturally occurring ROZs in Permian, Big Horn, Powder River, Williston Basins
• > 140 Billion bbls oil within ROZs in Permian Basin (Kuuskraa et al., 2013)
  – 27 billion economically recoverable via CO$_2$EOR
  – Success at Wasson, Seminole, Salt Creek, Goldsmith, Tall Cotton Fields (and others)
  – Net carbon negative oil
  • Large storage capacity
Motivation: ILB

• Are there ROZs within the ILB that have been historically overlooked?
• Can we use existing well logs to locate/characterize them?
  – Quick, cheap preliminary screening tool
  – Validate with more established methods
  – Are neutron density logs necessary?
• Test in study areas > extend to rest of basin
Ideal Saturation Curve

- 3 intervals
  - Separated by 2 depths
  - POWC
    - Mobile oil saturation
  - OWC
    - Water saturation reaches 100%
Ideal Saturation Curve

- Irreducible water saturation is 35%
- So at POWC is 50%  
  – Primary Recovery
Ideal Saturation Curve

- Irreducible water saturation is 35%
- So at POWC is 50%
  - Primary Recovery
- Residual oil saturation is 25%
  - Secondary recovery
  - (waterflood)
Ideal Saturation Curve

- Irreducible water saturation is 35%
- So at POWC is 50%  
  - Primary Recovery
- Residual oil saturation is 25%  
  - Secondary recovery  
  - (waterflood)
- CO$_2$EOR
Ideal Saturation Curve

• Characterize profile by:
  – Thickness of MPZ, ROZ, oil column
  – Median oil saturation within MPZ and ROZ
  – Oil saturation at POWC
Method

- **Water Saturation**
  - Archie
  - Ratio
  - Dual Water
- **“Proxy” curves**
  - Moveable Hydrocarbon Index
  - Bulk Volume Water
  - Apparent Water Resistivity
Method

• Water Saturation

  – Archie:
    \[ n \sqrt[5]{\frac{a \cdot R_w}{\phi m \cdot R_t}} \]

  – Ratio:
    \[ \left[ \frac{R_{xo} / R_t}{R_{mf} / R_w} \right]^{\frac{5}{8}} \]

  – Dual Water
Extra slides

- Use Pickett Plots to estimate $m$

\[ \text{Porosity} = \frac{1}{R_t} \]

- $R_w = 0.07$
- $a = 1.0$
- $m = 1.7$
- $n = 2.0$
Method

- “Proxy” curves

  - MHI
    \[ \frac{S_w}{S_{xo}} = \sqrt{\frac{R_{xo}/R_t}{R_{mf}/R_w}} \]

  - BVW
    \[ S_w \ast \emptyset \]

  - Rwa
    \[ \frac{\phi^m \ast R_t}{a} \]
Method
Noble Field

- Calculate and analyze curves for 94 wells
- Create maps and statistically analyze results to identify trends/outliers
- Validate with 4 pulsed neutron logs
- Use historical data to validate POWC/OWC
  - Producing perforations
  - Shows of oil on drilling records
  - Core reports
Thick Cypress Sandstone

- Detailed geologic characterization
- Thick, fairly homogenous clean sandstone
  - Good porosity and high permeability
  - Few shale breaks throughout
  - Calcite cement layers near oil water contact(s)
- Production from several formations including a thin MPZ above thick aquifer in thick Cypress
4 Example Wells

- Pulsed neutron logs on 4 previously drilled and logged wells taken in 2017

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Year Drilled</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Winter #4</td>
<td>2007</td>
<td>Good behind pipe oil saturation</td>
</tr>
<tr>
<td>Winter #7</td>
<td>2011</td>
<td></td>
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<tr>
<td>Foss #6</td>
<td>1994</td>
<td>Cypress Producer</td>
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<tr>
<td>Foss #7</td>
<td>2006</td>
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Example Well Log Analysis
Example Well Log Analysis
Example Well Log Analysis
Example Well Log Analysis (zoomed in)
Example Well Log Analysis (zoomed in)
Example Well Log Analysis (zoomed in)
Pulsed Neutron Saturation
Pulsed Neutron Saturation (zoomed in)
Archie Oil Saturation by Interval
Noble: Oil saturation in MPZ

![Graph showing oil saturation in Archie, Dual Water, and Ratio categories.]

- **Archie:** Oil saturation ranges from 30% to 50%.
- **Dual Water:** Oil saturation ranges from 30% to 50%.
- **Ratio:** Oil saturation ranges from 70% to 80%.

27
Noble: Oil saturation at POWC
Noble: Residual Oil Saturation
Noble Oil Isopach
Noble Results Overview

- Consistent results
  - Oil saturation at POWC ~40 - 45%
  - Residual oil saturation ~20 - 25%
- Reasonable trends
- Results match pulsed neutron logs
  - Same OWC, residual oil saturation
- Results match historical records
- Ratio $Sw$ too low
  - Fails at high water saturation?
Kenner West

• “mini” Noble
  – ~20 miles west
  – Similar rock and fluid properties

• 26 40s wells
  – SP + resistivity logs

• 9 90s wells
  – N/D porosity logs
Kenner Neutron Density logs

<table>
<thead>
<tr>
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<th>Noble</th>
<th>Kenner 90s</th>
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</thead>
<tbody>
<tr>
<td>MPZ So</td>
<td>55%</td>
<td>45%</td>
</tr>
<tr>
<td>So at POWC</td>
<td>45%</td>
<td>40%</td>
</tr>
<tr>
<td>Residual So</td>
<td>25%</td>
<td>25%</td>
</tr>
<tr>
<td>Count</td>
<td>94</td>
<td>9</td>
</tr>
</tbody>
</table>

![Bar chart comparing median oil saturation for MPZ, So@POWC, and ROS between Noble and Kenner 90s.](chart.png)
Kenner e-logs

- Can we use elogs to identify and characterize ROZ?
  - Ratio saturation failed
  - SP or SN derived porosity can be used in Archie
- IP: 4 bbls oil, 233 bbls water per day
## Kenner e-logs

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<th>Kenner 40s</th>
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<tbody>
<tr>
<td>MPZ So</td>
<td>55%</td>
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<td>45%</td>
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<td>So at POWC</td>
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### Diagram

- **40s**
  - Median Oil Saturation %
  - MPZ
  - So@POWC
  - ROS
Kenner Oil Isopach
Kenner Map all MPZ
Kenner Map 40s MPZ
Kenner Initial Condition Model
Kenner Initial Condition Model
Kenner Initial Condition Model
Conclusions

• Evidence of ROZs in the ILB
  – Within thick Cypress Sandstone at both Noble and Kenner West Fields

• Well logs can be used to find/characterize them

• Worked in this case but…
  – Important to validate with other methods
  – Because formation is homogenous and well understood?
Thank You

• Questions?
Acknowledgments

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• For project information, including reports and presentations, please visit: http://www.isgs.illinois.edu/research/ERD/NCO2EOR
Pulsed Neutron Comparison

- From other wells:
- So at POWC ~45%
- ROS ~25%

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<th>Pulsed Neutron</th>
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<tbody>
<tr>
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<tr>
<td>Winter #7</td>
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<td>2613</td>
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<tr>
<td>Foss #6</td>
<td>2603</td>
<td>2625</td>
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<tr>
<td>Foss #7</td>
<td>2600</td>
<td>2625</td>
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