Components and Processes Impacting Production Success from Unconventional Shale Resource Systems

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Acknowledgements

- Saudi Aramco and Aramco Services Corp.
  Their patented POPI technique is enhancing the understanding and completion of both conventional and unconventional reservoir systems.
Talk Outline

- Introduction
- Components and Processes Affecting Shale Resource Production
  - Source rock generation and organic porosity development
  - Adsorption and its role in retention, storage, and expulsion fractionation
  - Oil crossover effect (oil saturation index)
  - Producible oil index (oil saturation less adsorption indices)
- Summary of all organic, inorganic, core, geological and geophysical points

General Comments

- History of shale resource plays
  - 1800s first shale gas well in Fredonia, NY
  - Early 1900s to present Monterey Shale oil wells
  - 1980s to present Antrim Shale biogenic gas wells
- History of Stimulation
  - First stimulation in 1957
  - Over a million stimulated wells
  - 1980s to present -over 45,000 high energy stimulations on shale wells
- Mis-reporting of ground water contamination
  - The first information spits out condemnation, the facts prove the condemnations incorrect
  - e.g., water wells in Parker County, TX were contaminated with gas most likely for several millions of years prior to Range Resources drilling and stimulating the Barnett Shale; case dismissed – no contamination by Range proven by geochemistry of gases
- Economic impact: jobs, revenues
  - Eagle Ford Shale will create tens of thousands of jobs over the next decade
  - It will also generate billions in revenues for everyone: drillers, landowners, state/local governments, schools, citizens, ancillary service industries, and so forth
What is a Shale Resource System?

A shale resource system is any continuous organic-rich source rock with or without juxtaposed organic-lean lithofacies that can made to produce naturally generated petroleum via high energy stimulation.
Matrix and Organic Porosity

- **Doig**
  - \( y = -0.1879x + 5.1138 \)
  - \( R^2 = 0.2179 \)

- **Montney**
  - \( y = 0.3605x + 1.8536 \)
  - \( R^2 = 0.6842 \)

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Diagrammatic Illustration of TOC for a given kerogen type, e.g., Type II

- **Oil/Bitumen-Free TOC (wt.%)**
- **Generative Organic Carbon (wt.%)**
- **Non-Generative Organic Carbon (wt.%)**

- Responsible for generation of hydrocarbons
- Accounts for development of organic porosity
- Does not generate any appreciable amount of petroleum
- Does account for storage by adsorption
**Conversion of organic carbon (TOC) in wt.% to vol.%**

TOC is 7 weight percent, which is about 14 volume percent.

**Formation of Organic Porosity from Generative Organic Carbon**

**Assumptions:**
- 7.00 wt.% TOC$_{o}$
- 14.00 vol.% TOC$_{o}$
- TOC$_{o}$ is 37% GOC
- Kerogen density is: 1.1 g/cc GOC
- 1.4 g/cc NGOC

- 80% conversion of kerogen: 3.92%
- 100% conversion of kerogen: 4.90%

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Organic Porosity Development in the Barnett Shale

Loucks et al., 2009

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Why are no organic pores typically seen in the oil window?

Solubility of oil in kerogen and kerogen expansion

Supporting evidence consists of (1) oil extractable from rock and even isolated kerogen, and (2) aromatic fractionation in Bakken Shales versus expelled Bakken oils (Jarvie et al., 2011). Literature reports fractionation of aromatics from saturated hydrocarbons in kerogen swollen with different solvents (Ertas et al. 2011)

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**Fractionation of Generated Oils**

very important in hybrid systems

<table>
<thead>
<tr>
<th>Composition</th>
<th>% Sats</th>
<th>% Aros</th>
<th>% NSOs</th>
<th>% Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generated</td>
<td>55</td>
<td>19</td>
<td>26</td>
<td>100</td>
</tr>
<tr>
<td>Retained</td>
<td>44</td>
<td>12</td>
<td>44</td>
<td>100</td>
</tr>
<tr>
<td>Expelled</td>
<td>67</td>
<td>26</td>
<td>7</td>
<td>100</td>
</tr>
</tbody>
</table>

Expelled: 50% of saturates
Expelled: SS% of aromatics
Expelled: 14% of resins
Retained: 40% of saturates
Retained: 32° of aromatics
Retained: SG% of resins

Adsorption: ca.10 g petroleum per 100 g TOM

Sandvik et al., 1992

**For example, Ertas et al. (2006) data suggests fractionation of aromatics, which occurs in a comparison of Bakken Shale extracts versus Bakken sourced oils**

![Graph showing fractionation](image)

Paraffinicity Ratio (n-C7/Methylcyclohexane)

Aroma

Jarvie et al., 2011
Extraction of Whole Rock Samples often yields additional oil sorbed in rock matrix and kerogen; kerogen and asphaltenes sorb oil too.

Total oil is the sum of S1 + extractable S2 oil:
This shows that total oil is 2-3x S1 only.

TOC Distribution in Various Kerogen Types (in this case with fixed $TOC_0$)

Examples

**Type I**
- TOC = 10%
- HI = 900
- Live Carbon 75%
- Char

**Type II**
- TOC = 10%
- HI = 500
- Live Carbon 37%
- Char

**Type III**
- TOC = 10%
- HI = 200
- Live Carbon 25%
- Char
Spent TOC (only NGOC remains)

<table>
<thead>
<tr>
<th>Type</th>
<th>TOC</th>
<th>HI</th>
<th>GOC</th>
<th>NGOC</th>
<th>TOCspent</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>2.98%</td>
<td>0</td>
<td>8.5%</td>
<td>15.0%</td>
<td>22.2%</td>
</tr>
<tr>
<td>II</td>
<td>6.10%</td>
<td>0</td>
<td>42.5%</td>
<td>5.75</td>
<td>6.10</td>
</tr>
<tr>
<td>III</td>
<td>8.44%</td>
<td>0</td>
<td>17.0%</td>
<td>8.30</td>
<td>8.44</td>
</tr>
</tbody>
</table>

Percent GOC is HIoriginal / 1177 (assumes 85% carbon in petroleum/bitumen)
GOC is generative organic carbon
NGOC is non-generative organic carbon
TOCspent includes additional char formation

Nomograph of Iso-Decomposition Lines with iso-hydrogen indices for determining TOCoriginal

TOCspent = 15.0%
TOCoriginal = 22.2%
TOCspent = 8.5%
TOCoriginal = 12.2%
**Key to Producible Shale Oil Resource System?**

When high oil saturations are indicated –
the oil crossover effect

**Utilizing the “Oil Crossover Effect”:**

When the Oil Saturation Index > 100 mg oil/g TOC, producible oil is present.

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**Oil Content in Rock Sample as measured by thermal extraction**

Measured →

<table>
<thead>
<tr>
<th>S1 (oil)</th>
<th>S2 (kerogen)</th>
</tr>
</thead>
</table>

Reality →

<table>
<thead>
<tr>
<th>Evap. Loss of oil</th>
<th>S1 (oil)</th>
<th>S2 extracted rock</th>
<th>S1* (oil in S2)</th>
</tr>
</thead>
</table>

Overlap of free oil and oil carried over into S2
This is a function of oil type and isolated organic pores

**Total Oil** = (S1 whole - S1 extracted rock) + (S2 whole rock - S2 extracted rock) + E.L.

Evaporative Losses = S1 x (GC Fingerprint produced oil / GC Fingerprint of extracted oil)
This technique also allows prediction of GOR on shale (rock) samples.
Factors Affecting S1

- Type of sample (cuttings, SWC, core)
- Type of lithofacies (shale, carbonate, sandstone)
- Analytical instrument utilized for analysis
- Sample handling and processing (esp. heating)
- Oil-based mud (OBM) or organic additives to drilling fluids

Change in Various Geochemical Measurements due to age, sample type
(data from 1980s well and new offset well)

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Jarvie, 2012
**Parshall Field, Williston Basin**

**Bakken Shale, Reservoir and Oil Fingerprints**

**Key Observations**
1. U. Bakken Shale has lost very little oil, maybe less than the produced dead oil sample.
2. Middle Member has lost most hydrocarbons less than C15.

**Key Point**
- Shale holds the oil very tightly, whereas the dolomitic member retains very little light oil.

**Instrument factors on Oil Yield (S1)**

- Results in underestimating OIP by 1.5 million barrels at 100 ft thickness.

**Rock-Eval®** is a registered trademark of Institut Francais du Petrole.

**HAWK Resource Workstation®** is a registered trademark of Wildcat Technologies, Humble, Texas.

**POPI®** is a patented techniques and registered trademark of Saudi Arabian Oil Company.
Figure: Instrument factors on Oil Yield (S1)

Results in underestimating OIP by 6 million barrels at 100 ft thickness

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POPI® is a patented techniques and registered trademark of Saudi Arabian Oil Company.
Claims that RE-2 and RE-6 Pyrolysis Yields are different not substantiated by published IFP data

RE-2 and RE-6 data comparison in Behar et al., 2001. These data show high degree of correlation essential for compatibility of Rock-Eval® data.

Behar et al., 2001

Does carrier gas make a difference? depends on analysis...

- RE-6 uses nitrogen only
  - Advantages
    - Less likely to leak
      specific gravity 7x helium
    - Can be generated
  - Disadvantages:
    - Lower thermal conductivity
      5.7x lower than helium
    - Higher Tmax correction
      True Tmax 40° higher at 25°C/min
      - Important for kinetic measurements

- HAWK® uses either nitrogen or helium
  - Nitrogen for routine analysis including well site
  - Helium for kinetics
**Does Carrier Gas Mass Flow make a difference?**

- **HAWK** uses electronic mass flow controllers independent of gas pressure
- **SR Analyzer** uses manual pressure regulators to control gas flow; dependent on gas pressure only which can vary considerably

![Graph showing the relationship between Pyrolysis Carrier Gas Flow Rate and Kerogen (S2) Yield (mg kerogen/g rock)]

**RE2, RE6, Leco, and Elemental organic carbon analysis (TOC)**

TOC is consistent among all analytical techniques and no errors result in interpretive differences among kerogen types or source rock potential (the GOC portion of TOC is more important for generation, whereas NGOC is more important for organic storage).

Results from Behar et al., 2001, show that RE-6 TOC data can vary from elemental analysis by upwards of 10 wt.% TOC.

Leco TOC is inherently the best method for TOC measurements.

![Graph showing the relationship between Standard Rock-Eval and TOC yield]
Assessing Shale Resource Systems

**HAWK Resource WorkStation**

1. Designed for both laboratory and well site use
2. Determine oil carryover (oil in kerogen peak)
3. Determine lost oil due to evaporation from storage, handling, processing
4. Assess oil quality (API gravity, viscosity, GOR, sulfur, gas composition)
5. Determine TOC, total carbon, and carbonate carbon
6. Predict organic porosity
7. Determine OOIP or GIP (equivalency)
8. Built-in shale resource comparative database
9. Built in kinetics profiles for transformation rate prediction

![Diagram of HAWK Resource WorkStation](image)

**New HAWK Resource WorkStation**

Wildcat Technologies
Available Jan 2013

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**HAWK Resource Workstation**

comparison of resource with analog systems

![Graph showing comparison](image)

Thought to be a shale gas prospect but data is comparable to shale oil possibility if oil saturations (crossover) is sufficient
EOG Resources N&D 1-05H, Parshall Field
overpressured, commercial well

High Producible Oil Index

EOG Resources Fertile 1-12H
underpressured, non-commercial well

Low Producible Oil Index
Added Value of Predicted GOR values directly on shale samples

Parshall Field
Predicted GOR values

Sanish Field
Predicted GOR values

This prediction requires a GOR-GC analysis that uses C₆ and C₇ hydrocarbons that are used to predict GOR from organic-rich shale samples

Range of Understanding Needed for shale resource play assessment

Modified from King, 2010, SPE-133456
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