Large Scale Geologic Controls on Hydraulic Stimulation

John McLennan, University of Utah, Salt Lake City

CH EN 6158 Energy and Society

Hydraulic Fracturing Wellbore Integrity Offshore Operations

U.S. Primary Energy Consumption: By Fuel (1980-2040)

1 Btu = Heat to raise temperature of 1 lbm of water 1°F
1 therm = 100,000 Btu
10 therm = 1 dekatherm = 1,000,000 Btu
Gross Heating Value 1 scf CH₄ = 1,012 Btu/scf
Gross Heating Value 1,000 scf CH₄ = 1 dekatherm

http://www.eia.gov/forecasts/aeo/er/early_fuel.cfm

Shale: An Energy Game Changer

Name of your event, Date & Location
Why Has This Change Occurred?
Subsurface rock capable of containing oil, natural gas, water or other fluids

Reservoir Requirements
- Volume/Extent
- Storage Capacity
- Permeability

Low Permeability Reservoir
Subsurface rock capable of containing oil, gas, water or other fluids

Requirements
- Volume/Extent
- Storage Capacity
- Permeability

Implications
- Conductive Network
- Surface Area
- Low Permeability
- Methods?

Additional Surface Area:
Horizontal Drilling and Hydraulic Fracturing

Image After Trican Well Service

Name of your event, Date & Location
What is Hydraulic Fracturing?

- Fluid pumped into well faster than it can escape into formation
- Pressure rises and formation “breaks”
- Breakdown and early fracture growth expose new formation area to injected fluid
- If pumping rate maintained higher than fluid-loss rate newly created fracture propagates

Stages of Treatment

The Pad
- First part of treatment is fluid only - PAD
- Break down and initiate fracture
- Provides fluid to produce sufficient penetration and width to allow proppant-laden fluid stages to later enter

Keep The Fracture Open

The Propped Stages
- Solid particulates pumped with fluid to prop open fracture after pumping stops
- Proppant is sand or ceramic or maybe bauxite
- Proppant concentration increased with time
Base Hydraulic Fracturing Fluid

Proppant - To Maintain Conductivity

Blenders
What Has Changed?

Implications?

- Large Volumes of Water Required For Injection to Create Substantial Surface Area
- Substantial Storage, Supply and Transport Considerations
- High Injection Rates to Carry Proppant and Create Major Fracture Networks
- Substantial Hydraulic Horsepower

Forecasts for Hydrocarbon Production Sustainability of Hydrocarbon Production

Environmental Stewardship Economically Appropriate Geopolitically Secure

Name of your event, Date & Location
Sustainability

- Environmentally Appropriate
  - Extraction Footprint
  - Co-Utilization of Other Resources
    (Water, Food Stock ...)
  - Overall GHG Footprint
  - Induced Seismicity
  - Regulatory Balance
  - Atmospheric Modification/Mitigation
  - Public Health
  - Social Issues
- Economic
- Geopolitically Secure

Sustainability

- Environmental
- Economic
  - Industrial “Cyclcity”
  - Forecasting Difficulties
  - Co-Utilizing Resources
    (Water, Food Stock ...)
  - Cannot Rely on Subsidies
  - Royalties and Taxation
  - Regulatory Oversights
  - Process Control and Automation
- Geopolitically Secure

Sustainability

- Environmentally Appropriate
- Economic
- Geopolitically Secure
  - Domestic Obligations – Balanced Approach
  - Alleviate OPEC dependence
  - Iran’s Influence in Middle East
    - Russia’s Influence in Europe
  - Minimize Employment Cycles and Technology
    Cycles Associated with Energy Pricing

Name of your event, Date & Location
Forecasts for Hydracarbon Production Sustainability of Hydrocarbon Production Economic Viability

It is Harder Than it Looks

- “Successful” gas well producing 1 MMscf/D

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/Mscf</th>
<th>Cash Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price at Gas Terminal</td>
<td>$3.40</td>
<td></td>
</tr>
<tr>
<td><strong>TRANSPORTATION DISCOUNT</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pipeline to intermediate-stage gathering system</td>
<td>($0.10)</td>
<td>$3.30</td>
</tr>
<tr>
<td>(up to several miles)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fee to gathering system owner Gathering system tied into</td>
<td>($0.30)</td>
<td>$3.00</td>
</tr>
<tr>
<td>pipeline at meter station</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


It All Adds Up

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/Mscf</th>
<th>Cash Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transported on pipeline to gas processing plant</td>
<td>($0.50)</td>
<td>$2.50</td>
</tr>
<tr>
<td><strong>PIPELINE SPEC FOR SALE TO END USER</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remove water, carbon dioxide, hydrogen sulfide etc.</td>
<td>($0.90)</td>
<td>$1.60</td>
</tr>
<tr>
<td>and compress gas to pipeline operating pressures</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MARKETER CONTRACTS SPACE ON TRUNK LINES</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Name of your event, Date & Location
It All Adds Up

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/Mscf</th>
<th>Cash Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5% Royalties on Federal Land</td>
<td>($0.43)</td>
<td>$1.17</td>
</tr>
<tr>
<td>Operating Costs</td>
<td>($0.20)</td>
<td>$0.97</td>
</tr>
<tr>
<td>Administration: G&amp;A and Interest on Debt</td>
<td>($0.50-0.70)</td>
<td>$0.27</td>
</tr>
</tbody>
</table>

What Have We Forgotten?

- Finding, Development and Acquisition, or FD&A
- Optimistically this is $2 per Mscf
- Probably more like $3.50
- This Example: Breakeven Price $6.63
- Depletion, Depreciation and Accretion may be better indicator
  Cost to book proven reserves
- DD&A $4/Mscf - breakeven price $7.13/Mscf

Breakeven Pricing
Breakeven
(15% ATAX, excludes land, $90 oil, $4 gas)

International - Shale Gas Breakeven

Forecasts for Hydrocarbon Production
Sustainability of Hydrocarbon Production
Economic Viability
Environmental Concerns

Name of your event, Date & Location
Environmental and Public Health Issues

1. Extraction Footprint
2. Habitat Disruption
3. Co-Utilization of Resources (Water, Food Stock ...)
4. Induced Seismicity
5. Atmospheric Modification/Mitigation
6. Transportation
7. Refining
8. Regulatory Tightrope

Footprint – Degree of Surface Impact

<table>
<thead>
<tr>
<th>Issues</th>
<th>Regulations or Resolutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 1 to 5 acre pad for well construction</td>
<td>1. Reserve Pits</td>
</tr>
<tr>
<td>2. Access roads</td>
<td>2. Pad</td>
</tr>
<tr>
<td>3. Vertical well spacing at 80 acres and less</td>
<td>3. Drilling Rig</td>
</tr>
<tr>
<td>4. Deeper, longer wells and time to drill these wells</td>
<td>4. Rig Tower</td>
</tr>
<tr>
<td>5. Low Recovery Factors</td>
<td>5. Employee Trailers</td>
</tr>
</tbody>
</table>

Footprint – Degree of Surface Impact

<table>
<thead>
<tr>
<th>Issues</th>
<th>Regulations or Resolutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 1 to 5 acre pad for well construction</td>
<td>1. Reserve Pits</td>
</tr>
<tr>
<td>2. Access roads</td>
<td>2. Pad</td>
</tr>
<tr>
<td>3. Vertical well spacing at 80 acres and less</td>
<td>3. Drilling Rig</td>
</tr>
<tr>
<td>4. Deeper, longer wells and time to drill these wells</td>
<td>4. Rig Tower</td>
</tr>
<tr>
<td>5. Low Recovery Factors</td>
<td>5. Employee Trailers</td>
</tr>
</tbody>
</table>

Name of your event, Date & Location
Footprint – Degree of Surface Impact

Issues
- 110.5 acre pad for well construction
- Access roads
- Vertical well spacing at 80 acres and less
- Deeper, longer wells and time to drill these wells
- Low Recovery Factors


Footprint – Degree of Surface Impact

Issues
- Multiple wells per pad

http://outrunchange.com/2013/12/18/multiple‐wells‐on‐one‐site‐pad‐drilling/

Footprint – Degree of Surface Impact

Issues
- Improved Drilling (e.g., Top Drive)
- Longer horizontal and extended reach wells

Name of your event, Date & Location
Footprint – Degree of Surface Impact

**Issues**

**Regulations or Resolutions**

- Improved drilling (automation, steering, bits)

---

Footprint – Degree of Surface Impact

**Issues**

**Regulations or Resolutions**

- Automation, Geosteering

---

Habitat Disruption

**Issues**

- Particularly sage grouse in Western United States
- Certain flora in oil shale localities, for example
- Archaeological

**Regulations or Resolutions**

- Minimize footprint
- Minimize access roads
- Hide services
- Minimize drilling time
- Noise abatement
- Dust suppression
- Centralized facilities

---

Name of your event, Date & Location
Co-Utilization of Resources

**Issues**
- Large volumes of water can be required for hydraulic fracturing
- Substantial Storage, Supply and Transport Considerations
- High Injection Rates to Carry Proppant and Create Major Fracture Networks
- Substantial Hydraulic Horsepower

**Regulations or Resolutions**

---

Co-Utilization of Resources

**Issues**

---

Co-Utilization of Resources

**Issues**

---

Guar gum or guaran, is a galactomannan
Primarily ground endosperm of guar beans

---

Name of your event, Date & Location
Co-Utilization of Resources

Issues

- Surface processing
- Fluid reformulations
- Reuse fracturing fluids
- Beneficial reuse of extracted solids
- Local Example: Newfield water purification before water flooding
- Newer bactericides

Regulations or Resolutions

http://www.deq.utah.gov/Business_Assistance/insert_business/guides/oilgas/water.htm

Drilling, Completion and Production Fluids

Issues

- Oil-based drilling fluids sometimes preferable even if more costly
- Flowback water often has high salt concentrations and may even include NORMS (Eastern U.S.)
- Small percentages of biocides, surfactants, corrosion and scale inhibitors

Regulations or Resolutions

http://www.newfield.com/in-the-news.aspx#story8

Name of your event, Date & Location
Drilling, Completion and Production Fluids

Issues
- Oil-based drilling fluids sometimes preferable even if more costly
- High NGL and NOG
- Small water content

Induced Seismicity

Issues
- Injection of Produced or Flowback Water
- Potential for Reactivation of Metastable Faults

Induced Seismicity

Issues
- Potential for Reactivation of Metastable Faults
- Typically Larger Volumes in Disposal Wells
- Have been some reported incidents correlated with large volume injection
- How does fault reactivation occur?
- Shearing Stresses are Driving Reactivation
- Effective Normal Stress Causes Frictional Resistance to Movement

Name of your event, Date & Location
Induced Seismicity

Issues

Regulations or Resolutions
- Geologic Control and Insight
- Monitoring and Prediction
- Controlling Injection Parameters in Specific Geologic Regimes
- No underground disposal?
- All water recycled?

Atmospheric Modification

Issues
- Road Dust
- Atmospheric Particulates
- Volatile Organic Compounds
- Ozone
- Methane Leakage
- Fugitive Gas

Regulations or Resolutions
- Dust Suppression
- CNG Fleets
- Volatile Recycling Units
- Centralizing Processing
- Improved Well Construction
- Reduced Vehicular Traffic
- Additional Automation
- Rationale Leak Detection

Name of your event, Date & Location
Atmospheric Modification

Issues

Road Dust

Best Management Practices for the Oil and Gas Industry

- Use enclosed tanks, central or on-site water treatment facilities instead of open pits to reduce fugitive air emissions.
- Minimize venting and/or use closed loop processes where practical during “flow downs.”
- Install a pressure relief system for temporary fluids from wells or “flow downs.”

Regulations or Resolutions

Road Dust Suppression

CNG Fleets

Volatile Recycling Units

Centralizing Processing

Improved Well Construction

Reduced Vehicular Traffic

Additional Automation

Rationale Leak Detection

Midstream – Transportation

Downstream - Refineries

Issues

- Pipeline Routing
- Pipeline Integrity
- Pipeline Availability
- Pipeline Viability
- Pipeline Monitoring
- Flaring
- Fugitive Gas
- Low Margins
- Waxy Crude

Regulations or Resolutions

Well Integrity

- Leaky Wellbores
- Quality Control on Cementing
- Location and Abandoning Legacy Wells

Name of your event, Date & Location
In this figure, all casing strings cemented to surface.

Not with thin bypassed gas zones!

Name of your event, Date & Location

Energy & Geoscience Institute
A UNIVERSITY OF CALIFORNIA INSTITUTE
**Example: Thin Gas Sands**

Depth to top of formation is from 300 to 600 m

---

**Forecasts for Hydrocarbon Production**

- Sustainability of Hydrocarbon Production
- Economic Viability
- Environmental Concerns
- Technology
- Environmental Stewardship

---

**Challenges and Opportunities**

**To Alter the Status Quo**

**Favorable Economics**

- Harder to do now by economies of scale, automation and negotiating with vendors
- Opportunities for Technology Developments
- Remember Finding and Well Construction Costs

---

**Insert the name of your Presentation here**

**Room for 2 lines at 16pt font**

---

**Name of your event, Date & Location**
Challenges and Opportunities
To Alter the Status Quo
Minimize Environmental Consequences
- Reduced Footprint
- Efficient Well Construction
- Low Volume Stimulation
- Recycling
- Seismicity
- Wellbore Integrity

Macondo Prospect
The April 20th, 2010 accident involving Transocean’s Deepwater Horizon drilling vessel and BP’s Macondo well (Mississippi Canyon Block 252, MC252) claimed 11 lives

Name of your event, Date & Location
Macondo Prospect

- October 21, 2009, Transocean Marinas semi submersible arrived on location to spud exploration well
- Several days later drilling commenced
- Halted on Nov. 28, 2009, when the semi submersible underwent repairs for damage caused by Hurricane Ida.
- BP leased another rig, Deepwater Horizon semi submersible to complete drilling operations on the well.
- Deepwater Horizon semi submersible commenced operations in February 2010 and had recently terminated drilling at a depth of just over 18,000 feet (5,486 meters). ....

Chronology

- February 15, 2010 – Drilling begins. Planned well to be drilled to 18,000 feet below sea level, and plugged and suspended for subsequent completion as subsea producer.
- April 9 - Drills last section with TD at 18,360 feet MSL
- Last 152 feet need casing. Liner/tieback casing that will provide 4 redundant barriers to flow recommended. Single liner with fewer barriers used.
- April 17 - Well being prepared to be cemented and TA. Blowout preventer is tested and found to be "functional."
- April 18 – Schlumberger flies a crew to conduct a cement bond log to determine whether the cement has bonded to the casing and surrounding formations. Not run.
- April 19 - Halliburton completes cementing of the final production casing string.
- April 20 - 9:45 p.m.
- April 22 10:21 am - Rig sinks.

A sister rig, the Nautilus, being transported on a Heavy-Lift vessel

L and R, the Deepwater Horizon on location in better days

Name of your event, Date & Location
Chronology

- February 15, 2010 – Drilling begins. Planned well to be drilled to 18,000 feet below sea level, and plugged and suspended for subsequent completion as subsea producer.
- April 9 - Drills last section with TD at 18,360 feet MSL
- Last 1,192 feet need casing. Liner/tieback casing that will provide 4 redundant barriers to flow recommended. Single liner with fewer barriers used.
- April 17 - Well being prepared to be cemented and TA. Blowout preventer is tested and found to be “functional.”
- April 18 - Schlumberger flies a crew to conduct a cement bond log to determine whether the cement has bonded to the casing and surrounding formations. Not run.
- April 19 - Halliburton completes cementing of the final production casing string.
- April 20 - 9:45 p.m.
- April 22 10:21 am - Rig sinks.

Name of your event, Date & Location
Casing and Cementing

---

**Blowout Preventer**
- One or more valves installed at wellhead to prevent escape of pressure either in annular space between casing and drill pipe or in open hole (for example, hole with no drill pipe) during drilling or completion operations.

---

**Flash Drilling and Complete Logging**

---

Name of your event, Date & Location
Insert the name of your Presentation here
Room for 2 lines at 16pt font

Name of your event, Date & Location
Name of your event, Date & Location

Energy & Geoscience Institute
Insert the name of your Presentation here
Room for 2 lines at 16pt font

Smoke from the Deepwater Horizon Oil Rig can be seen in this GOES-13 satellite image taken at 23:15 UTC on April 21, 2010. Twelve people were missing and seven critically injured after an explosion and fire occurred around 13hrs last night at the oil-drilling rig located about 40 miles off the Louisiana coast. The Coast Guard is still searching for the missing people.

Name of your event, Date & Location

[Image of the Deepwater Horizon oil rig burning in the ocean]

[Map showing the location of the Deepwater Horizon oil rig, Louisiana, Texas, Florida, and Mississippi]
Chronology

• May 7 - A 125-tonne (280,000 lb) container dome is lowered over the largest of the well leaks and pipe the oil to a storage vessel on the surface.
• May 8 - BP reports that hydrates forming at top of dome making it ineffective.
• May 10 - Plans to apply five feet in diameter containment vessel nicknamed “top hat”. BP announces plans for “junk shot”
• May 14 - BP inserts 4-inch riser into 21-inch riser.
• May 26 - BP announces plan for “top kill”
• May 29 - BP declares Top Kill is a failure and moves on to their next contingency option, the Lower Marine Riser Package (LMRP) Cap Containment System.
• May 31 - BP announces plan to cut riser, placing a cap on it and channeling the oil to surface ships.

Name of your event, Date & Location
Chronology

- May 7 - A 125-tonne (280,000 lb) container dome is lowered over the largest of the well leaks and pipe the oil to a storage vessel on the surface.
- May 8 - BP reports that hydrates forming at top of dome making it ineffective.
- May 10 - Plans to apply five feet in diameter containment vessel nicknamed "top hat". BP announces plans for "junk shot".
- May 14 - BP inserts 4-inch riser into 2-inch riser.
- May 16 - BP reports that hydrates forming at top of dome making it ineffective.
- May 19 - BP announces plans for "top kill".
- May 20 - BP declares Top Kill is a failure and moves on to their next contingency option, the Lower Marine Riser Package (LMRP) Cap Containment System.
- May 31 - BP announces plan to cut riser, placing a cap on it and channeling the oil to surface ships.
Chronology

- July 10 - Old cap removed from well at 12:37 p.m.
- July 12 - Three ram capping stack installed on Deep Water Horizon LMRP at 7 p.m. The stack completes the installation of the new 40-ton containment device sealing cap. Tests begin on testing well integrity.
- July 15 - BP test cuts off all oil pouring into the Gulf at 2:25 pm.
- "Static kill" by bullheading fluid into hole
- Leak was successfully shut-in on August 4, 2010 by a "static kill"
- Two relief wells for bottom kill

Static and Bottom Kills

Static Kill Operation

Name of your event, Date & Location

EGI
Energy & Geoscience Institute
AT THE UNIVERSITY OF WASHINGTON

35