Overview - Hydraulic Fracturing Process

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Omar B. Milligan Professor and Director
Petroleum Engineering Program
University of Southern California
The Dawn of Tapping Unconventional Reservoirs
U.S. Experience

- Barnet: Discovery 1998, Development 2003
- Marcellus: Discovery 2002, Development 2006
- Woodford: Discovery 2003, Development 2007
- Fayetteville: Discovery 2003, Development 2007
- Haynsville: Discovery 2005, Development 2008
- Eagle Ford: Discovery 2009, Development 2012
Shale Gas and Oil Resources
• What is Hydraulic Fracturing?
• Why do we fracture rocks?
• Where are the fracturing operations?
• What are the targets in California?
Pore spaces to retain hydrocarbon.

Permeability allowing the fluid to move.

Conventional Rocks

Unconventional Rocks
Shale Rocks
Nearly Solid Chert
Hydraulic Fracturing
Horizontal Drilling
Horizontal Drilling and Fracturing
Is it a New Concept?
Klepper Gas Unit No. 1, Hugoton field, Kans. The first well to be hydraulically fractured to increase well productivity.

(SPE Monograph Vol. 2)
The Great Race
First Commercial Fracturing Treatment – 1949 (Pictured)
Stephens County, OK - Dwight K. Smith – Halliburton Engr.

1949

Second Commercial Fracturing Treatment – 1949 – 2 Hours Later
Archer County, TX - A. B. Waters – Halliburton Engr.

Courtesy - Halliburton
Co-Inventors of Hydraulic Fracturing

Patented May 13, 1952

2,596,844

UNITED STATES PATENT OFFICE

2,596,844

TREATMENT OF WELLS

Joseph B. Clark, Tulsa, Okla., assignor to Stanolind Oil and Gas Company, Tulsa, Okla., a corporation of Delaware

No Drawing. Application December 31, 1949,
Serial No. 136,394
23 Claims. (Cl. 166—21)

This invention pertains to the treatment of oil and gas wells. More particularly, this invention pertains to a method of increasing the productivity of an oil or gas well by providing lateral drainage channels in selected formations adjacent a well. This application is a continuation-in-part of my application Serial Number 29,932, filed May 28, 1948.
How do we keep the fractures open?
How do we Transport the proppants?
2% Additives

- Acid
- Anti-bacterial Agent
- Breaker
- Clay Stabilizer
- Corrosion Inhibitor
- Crosslinker
- Friction Reducer
- Gelling Agent
- Iron Control
- pH Adjusting Agent
- Scale Inhibitor
- Surfactant
- Hydrochloric acid (HCl)
- Gelling agents, vegetable derived guar gum,
- Oxidizers
- Biocides
- Methanol prevents polysaccharide gels degrading above temperatures of 200°F.
Process Description
THE “TYPICAL” TREATMENT – STEP 1

INITIATING THE FRACTURE

Ralph W. Veatch
THE “TYPICAL” TREATMENT – STEP 2

EXTENDING THE FRACTURE AND INJECTING THE PROPPANT

Ralph W. Veatch
THE “TYPICAL” TREATMENT – STEP 1

BACK FLOWING THE FRACTURING FLUID

WELLHEAD

UNPROPPED FRACTURE AREA

TUBING

PAY

PROPPED FRACTURE AREA

Ralph W. Veatch
Hydraulic Fractures: Transverse vs Longitudinal

Fig. 2—Well Types and Orientation of Hydraulic Fractures

Typical vertical well

Horizontal well with Transverse Fractures

Horizontal well with Longitudinal Fractures

SPE 133511
Has the technology been used in California during the last several decades?
Lost Hills
Horizontals with Longitudinal and Transverse Fractures, West Flank South Belridge

Fig. 19—Pilot Program, West Flank Project
New Look at the Monterey Formation
Tar Seeps Closeup at Carpinteria State Beach
Primary laminations
Thin beds
San Pedro Basin - Santa Ana Mountains

(Y) West
Palos Verdes Hills
Pacific Ocean
Footwall
Late Miocene

(Wilmington Graben)
Palos Verdes Fault
Newport - Inglewood F.Z.

(Capistrano Embayment)
Cristianitos Fault

(Y') East
0 km
10
20

(not all features to scale)
(horizontal = vertical scale)

Catalina Schist (Franciscan belt)
Peninsular Ranges granitic WFH belt
Fore-arc (GVS belt)
Eocene-E. Miocene Sespe-Vaqueros
Miocene San Onofre Breccia
Miocene igneous rocks
Miocene strata

Crouch & Suppe (1993)
Figure 26
Occurrence of Monterey and Related Siliceous Rocks

After Ingle, 1981
Monterey Formation in California

- Onshore reservoirs
- Offshore Reservoirs
- Onshore source rock
• Santa Maria Basin
• Offshore Fields-Monterey as a Reservoir Rock
• Onshore Permeability Issue (Monterey as a reservoir and source rock)
Maturity Index
### California Monterey

#### Company Net Acreage

<table>
<thead>
<tr>
<th>Company</th>
<th>Net Acreage</th>
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<tbody>
<tr>
<td>Berry Petroleum</td>
<td>6,500</td>
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<tr>
<td>National Fuel Gas Company (NFG)</td>
<td>14,000</td>
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<tr>
<td>Occidental Petroleum Company (Oxy)</td>
<td>873,000</td>
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<td>Plains Exploration and Production</td>
<td>70,000</td>
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<td>Venoco</td>
<td>158,000</td>
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#### Table 57 Monterey/Santos Average EUR and Area

<table>
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<tr>
<th>Active</th>
<th>Active</th>
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<tbody>
<tr>
<td>Area (sq. miles)</td>
<td>1,752</td>
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<tr>
<td>EUR (MBO/ well)</td>
<td>550</td>
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<tr>
<td>Well Spacing (wells/ sq. mile)</td>
<td>16</td>
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<tr>
<td>TRR (BBO)</td>
<td>15.42</td>
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### Table II. U.S. Technically Recoverable Shale Oil Resources Summary

<table>
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<tr>
<th>Play</th>
<th>Technically Recoverable Resource</th>
<th>Area (sq. miles)</th>
<th>Average EUR</th>
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<tr>
<td></td>
<td>Gas (Tcf)</td>
<td>Oil (BBO)</td>
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<tr>
<td>Eagle Ford</td>
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<td>3.35</td>
<td>3,323</td>
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<tr>
<td>Total Gulf Coast</td>
<td>...</td>
<td>3.35</td>
<td>3,323</td>
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<tr>
<td>Avalon &amp; Bone Springs</td>
<td>...</td>
<td>1.58</td>
<td>1,313</td>
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<tr>
<td>Total Southwest</td>
<td>...</td>
<td>1.58</td>
<td>1,313</td>
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<tr>
<td>Bakken</td>
<td>...</td>
<td>3.59</td>
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<tr>
<td>Total Rocky Mountain</td>
<td>...</td>
<td>3.59</td>
<td>6,522</td>
</tr>
<tr>
<td>Monterey/Santos</td>
<td>...</td>
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<td>1,752</td>
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<tr>
<td>Total West Coast</td>
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<tr>
<td>Total Lower 48 U.S.</td>
<td>...</td>
<td>23.94</td>
<td>12,910</td>
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**EIA estimates**
Concerns and Mitigation Measures

Atmospheric Emissions

Groundwater Protection

Wellbore/Seal Integrity

Ground Motion Response

Modified
NETL
- Better rock potential evaluation tools
- Better well course planning
- Better geosteering tools
- Advanced micro seismic monitoring

Today’s Technology