Hydraulic Fracturing & Water Use

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July 30, 2018
Onshore Wells

BP's biggest onshore UK oil well at Wytch Farm, Poole Harbour. Photo: BNPS
Offshore Wells

Land rig

Platform rig

(150 / 200 m)

Jack up

(150 m)

Semi sub & Drilling ship (Anchored)

(1000 - 1500 m)

Semi sub & Drilling ship (Dynamic pos.)

(3000 m)

Courtesy: Magnific.biz
What Is Hydraulic Fracturing?

Is a well stimulation technique through which the rock is fractured by injecting a pressurized fluid to optimize oil and gas production.

https://www.youtube.com/watch?v=_jBtP1C3C-0
Fracturing History

- **1947** – Klepper Gas Unit No. 1, Hugoton Field, Kansas. The first well fractured to increase production.

- **1949** – First & Second Commercial Fracturing Treatments, Stephens County, OK – and, Archer County, TX.
Hydraulic Fracturing Process

- Fluid injection through a wellbore into the formation at a pressure higher than the formation parting pressure (minimum stress also known as the closure stress)
- The fluid must be pumped well faster than it can escape (leak off) into the formation
Well & Fracture Orientation

$2q_i$

$q_i$ $q_i$
Fracture Complexity - Tectonic Regime/Well Productivity

Complexity increase due to tectonic activity (in-situ stress regimes)

Productivity decrease

After Potocki, 2012, SPE 162814
Fracture Mapping [SPE 77441]

- Geology: Mississippian age
- Extremely low permeability \((7 \times 10^{-5} - 5 \times 10^{-3} \text{ md})\) Barnett shale (North Texas)
- Formation height \(\sim 200-300\text{ft}\) (500 ft in the core area)
- Understanding the fracture geometry critical to the stimulation effectiveness and infill drilling program
- New method of Micro-seismic (MS) evaluation combined with surface and downhole tilt mapping
- Abnormally pressure formation
Fracture Mapping [SPE 119896]

Primary frac direction (red) roughly N45°E, secondary (blue) is N 45°W plane.

Up to 3 frac directions have been recorded.

Contact Area > 10 million ft$^2$.

Spacing of fractures:
N45E Primary: 60 - 70 ft
N45W Secondary: 70 - 80 ft

Acoustic Emissions (AE) & Fracture Geometry

Roberto Rivera Suarez et al., IPTC, Beijing 2013
Experimental Results

Effect of Wellbore Inclination with Isotropic Horizontal Stress

\[ \sigma_v = 1,200 \text{ psi}; \sigma_H = 780 \text{ psi}; \sigma_h = 780 \text{ psi} \]
\[ \alpha = 30^\circ, 45^\circ, 60^\circ; \beta = 0^\circ \]

In a stress state with equal horizontal stresses:
- the fracture initiates and propagates along the wellbore axis
- It is possible to produce bi-wing fractures
• Example 4

**Figure 17** - Small Block Test ($\alpha = 60^\circ$, $\beta = 45^\circ$, $\sigma_2$ [NS] = 260 psi, $\sigma_4$ [EW] = 1,200 psi, $\sigma_1$ [TB] = 780 psi)
Frac System Components

- **Frac Fluid** – Most fracs fluids are water based.
- **Proppant** – natural sand and a man made

![Pie chart showing composition of frac fluids.](chart.png)

- Water = 95.1%
- Sand = 4.8%
- Chemicals = 0.13%

Total chemicals on location is usually 1300 gallons, much of it water based.
Fracturing Fluids Systems

**WATER**

**Gelling agents**
- Cellulose
  - Hydroxy Ethyl
  - Carboxy Methyl
- Guar
  - Natural
  - Modified
  - Improved
  - ...

**Cross linking agents**
- Titanium
- Zirconium
- Aluminum
- Chromium
- Antimony
- Boron
- ...

**Additives**
- Antifoaming
- Defoamers
- Buffers
- Breakers
- Bacteria control
- Clay stabilizing
- Demulsifiers
- Fluid loss
- Friction reducing
- Scale inhibitors
- pH Control
- Surfactants
- Temperature stabilizers
- ...

## Most Common Additives

<table>
<thead>
<tr>
<th>Additives</th>
<th>Composition</th>
<th>Alternate Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friction reducer</td>
<td>Polyacrylamide</td>
<td>Adsorbent in baby diapers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flocculent in drinking water preparation</td>
</tr>
<tr>
<td>Biocide</td>
<td>Glutaraldehyde</td>
<td>Medical disinfectant</td>
</tr>
<tr>
<td>Alternate Biocide</td>
<td>Ozone, Dioxide UV,</td>
<td>Disinfectant in municipal water supplies</td>
</tr>
<tr>
<td></td>
<td>Chlorine</td>
<td></td>
</tr>
<tr>
<td>Gellants</td>
<td>Cellulose, Guar</td>
<td>Thickening ice cream and soups</td>
</tr>
<tr>
<td>Surfactants</td>
<td>Various</td>
<td>Cleaners, dish soaps</td>
</tr>
<tr>
<td>Scale Inhibitor</td>
<td>Polymers, Phosphonate</td>
<td>Some cleaners and medical treatment for bone issues</td>
</tr>
</tbody>
</table>

Post those fracs in [www.fracfocus.com](http://www.fracfocus.com)
Fracturing Fluids Characteristics

- Capable to transport the *propping agent* in the fracture
- Compatibility with the formation rock and fluid
- Capable to generate sufficient pressure drop along the fracture to create fracture width
- Minimize friction pressure losses during injection
- Use approved chemical additives to comply with environmental regulations
- Capable to control-breakdown to a low-viscosity fluid for cleanup (backflow) post treatment
- Cost-effective
Cross-Linked Fluids
Frac Types – Fluid System Trends

<table>
<thead>
<tr>
<th>Frac Type</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>Treatment type that uses a gelling agent and one or more crosslinkers in order to transport proppant into a hydraulic fracture.</td>
</tr>
<tr>
<td>Water Frac</td>
<td>Treatment type that uses a friction reducer, a gelling agent or a viscoelastic surfactant in order to transport proppant into a hydraulic fracture.</td>
</tr>
<tr>
<td>Hybrid</td>
<td>Treatment type that uses a combination of a friction reducer, gelling agent, acid gelling agent, or one or more crosslinkers in order to transport proppant into a hydraulic fracture.</td>
</tr>
<tr>
<td>Energized</td>
<td>Treatment type that incorporates an energizer, normally nitrogen or carbon dioxide, into the base fluid in order to generate foam that transports proppant into a hydraulic fracture.</td>
</tr>
<tr>
<td>Other/Unknown</td>
<td>Treatment type category that includes the following less common treatment types: Acid Frac, Gas Frac, Matrix Acidizing. This category also includes records for which a classification was unknown or unavailable generally due to incomplete data.</td>
</tr>
</tbody>
</table>
Fluid System Trends

US Aggregate Frac Types (% of total wells) vs. Oil Rig Count (% of total rigs)

Source: Baker Hughes; FracFocus.org
Hydraulic Fracturing Proppant (Sand)

Source: Shutterstock.com
Fracturing Proppant

- Silica sand ("frac sand")
- Ceramic proppants
- Resin coated proppants
Fracturing Proppant

Highest EUR, Production, IRR

High strength
Uniform size and shape
Thermal resistant

Tier 1 - High Conductivity
Ceramic

Medium strength
Irregular size and shape

Tier 2 - Medium Conductivity
Resin Coated Sand

Low strength
Irregular size and shape

Tier 3 - Low Conductivity
Sand
Typical Proppant Size

- 20-40 mesh (840 µm - 420 µm)
- 30-50 mesh (590 µm – 300 µm)
- 40-70 mesh (420 µm - 210 µm)
- 70-140 mesh (210 µm - 105 µm)
- 100 mesh (149 µm)
Proppant Transport

Patankar, 2002, reported by Palisch, 2008, SPE 115766
Fracturing Conventional vs Unconventional

Conventional Reservoirs:
- Small volumes that are easy to develop

Unconventional Reservoirs:
- Large volumes that are difficult to develop

Increased pricing and improved technology lead to the development of unconventional reservoirs.

Conventional: <20% OOIP
IOR: 20% - 40% OOIP
EOR: 30% - 50% OOIP

Enhanced oil production at Weyburn
- CO₂ injection

Barry Stephens, 2014
Fracture Monitoring

- Downhole gauges
  - Pressure/Rate
- Fiber optics
  - Flow rate/Temperature (every foot along the well) – even when the well is being frac’d
- Radioactive tracers are selected to have
  - the readily detectable radiation
  - appropriate chemical properties
  - and a half life and toxicity level that will minimize initial and residual contamination
  - radioactive isotopes chemically bonded to glass (sand) and/or resin beads may also be injected to track fractures
- Microseismic monitoring
  - Estimate fracture size and orientation (geophones placed in monitoring well) – mapping of seismic events locations – approximate fracture geometry
- Tiltmeteres (arrays placed on the surface or downhole)
  - Monitoring formation strain during fracturing
Other Use of Hydraulic Fracturing

- To stimulate groundwater wells
- To dispose waste by injection deep into rock
- To measure stress in the Earth
- To increase injection rates for geologic sequestration of $\text{CO}_2$
Challenges and Opportunities

• Surface handling of water & solids
• Slurry additives (food grades)
• HF treatment monitoring
• Cementing QC/QA
• Induced seismicity
• New technologies
  • Energized fractures
  • Reduced stimulation rate
  • Thermal treatments
• Reduction of treatment volume:
  • Increase fracturing efficiency
  • Flowback and forecasting improvement
Categories of Water Use

Source: https://water.usgs.gov/watuse/
Water Use

Source: https://water.usgs.gov/watuse/
Water Use

Source and use of freshwater in the United States, 2010

Source: https://water.usgs.gov/watuse/
Water Use

Total Water Withdrawals in the United States, by Category, 2010

- **Public supply**: 37% of 15,700 Mgal/d
  - Groundwater: 63%
  - Surface water: 26,300 Mgal/d

- **Domestic**: 96% of 3,540 Mgal/d
  - Groundwater: 64 Mgal/d

- **Irrigation**: 43% of 49,500 Mgal/d
  - Groundwater: 65,900 Mgal/d

- **Livestock**: 60% of 1,200 Mgal/d
  - Groundwater: 797 Mgal/d

- **Aquaculture**: 18% of 1,320 Mgal/d
  - Groundwater: 7,610 Mgal/d

- **Industrial**: 19% of 2,950 Mgal/d
  - Groundwater: 13,000 Mgal/d

- **Mining**: 27% of 3,910 Mgal/d
  - Groundwater: 1,410 Mgal/d

- **Thermoelectric power**: <1% of 721 Mgal/d

Source: [https://water.usgs.gov/watuse/](https://water.usgs.gov/watuse/)
Water Use

Source: [https://water.usgs.gov/watuse/](https://water.usgs.gov/watuse/)
Water Use Trends


Source: https://water.usgs.gov/watuse/
Typical Hydraulic Fracturing Fluid System

Source: https://water.usgs.gov/watuse/
How Much Water Does US Fracturing Really Use?

Study finds that Water used in fracking makes up less than one percent of total industrial water use nationwide.

Energy companies used nearly 250 billion gallons of water to extract shale gas and oil from hydraulically fractured wells in the US between 2005 and 2014, a new study finds. During the same period, the fracked wells generated about 210 billion gallons of wastewater. As large as those numbers seem, the study calculates that the water used in fracking makes up less than one percent of total industrial water use nationwide.

Tracking Flow Back

- Tracked with $SO_4$ ion
- Frac Water Load Recovery
- 3 to 6 bpm (120 to 250 gallons per min) for 1 to 3 days - tapers off to less than 300 gallons per day.
- Gas flow starts
- Formation water (usually $< .10$ to $20$ bwpd)
- Tracked with Chlorides
- Gas flow starts
- Production stability

Timeline (increasing volume of returns)

George King Training 2017
# Produced & Brine Water Sources

<table>
<thead>
<tr>
<th>Water Type</th>
<th>Total Dissolved Solids (TDS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PPM</td>
</tr>
<tr>
<td>Fresh</td>
<td>&lt;1000</td>
</tr>
<tr>
<td>Brackish (can be used)</td>
<td>1000 – 3000</td>
</tr>
<tr>
<td>Brackish High</td>
<td>5000 – 15000</td>
</tr>
<tr>
<td>Saline</td>
<td>15000 - 30000</td>
</tr>
<tr>
<td>Sea water</td>
<td>30000 - 50000</td>
</tr>
<tr>
<td>Brine</td>
<td>40000 – 30000+</td>
</tr>
</tbody>
</table>

*Modified from George King SPE – GCS Oct. 27, 2011*
### Water Management: Quantities Flowed Back in Shale Reservoirs (Ranges)

<table>
<thead>
<tr>
<th>Basin or Area</th>
<th>% Frac Water Recovered</th>
<th>Typical Frac Volume Used (Gal.)</th>
<th>Typical Chemical % in Frac</th>
<th>Chemical % in Flowback (Gross Est.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnett</td>
<td>30 to 50%</td>
<td>4 to 5 mm</td>
<td>0.2%</td>
<td>&lt;0.05%</td>
</tr>
<tr>
<td>Devonian</td>
<td>40 to 50%</td>
<td>4 to 5 mm</td>
<td>0.2%</td>
<td>&lt;0.1%</td>
</tr>
<tr>
<td>Eagle Ford</td>
<td>5 to 10%</td>
<td>4 to 5 mm</td>
<td>0.3 to 0.4% (Hybrid Frac)</td>
<td>&lt;0.2% (polymer dominated)</td>
</tr>
<tr>
<td>Fayetteville</td>
<td>30 to 60%</td>
<td>3 to 4 mm</td>
<td>0.2%</td>
<td>&lt;0.05%</td>
</tr>
<tr>
<td>Haynesville</td>
<td>5 to 15%</td>
<td>4 to 6 mm</td>
<td>0.3% (Hybrid Frac)</td>
<td>&lt;0.1% (polymer dominated)</td>
</tr>
<tr>
<td>Horn River</td>
<td>30 to 50%</td>
<td>10 to 12 mm (95% from salt water supply wells)</td>
<td>&lt;0.1% (Apache)</td>
<td>&lt;0.05%</td>
</tr>
<tr>
<td>Woodford</td>
<td>30 to 50%</td>
<td>4 to 5 mm</td>
<td>0.2%</td>
<td>&lt;0.05%</td>
</tr>
</tbody>
</table>

Sources: SPE 133456, SPE 152596, George E. King’s communication with operators in these basins. Also SPE papers on produced water treating.
Water Use and Management

- Water requirements for fracture stimulation low relative to other users.

**Freshwater Users in the Barnett Shale Region**

- Recover < 50% of injected fluids during flowback.
- Disposal is the big issue.

Source: Water Demand chart from Southwestern Energy website. Freshwater users chart Natural Gas: The Path to Clean Energy Forum Hydraulic Fracturing a Historical and Impact Perspective, Kent Perry GTI 2010
Where Are We Fracturing?

Number of Disclosures for Top 10 States
Jan 2011 – Oct 2013

Source: ALL Consulting, SPE 168640

Number of Disclosures for Top 10 Plays
Jan 2011 – Oct 2013
Water Usage (Processed) – Permian Basin

- Horizontal Gas: 4.8 million gallons
- Horizontal Oil: 3.2 million gallons
- Vertical Gas: 0.7 million gallons
- Vertical Oil: 0.5 million gallons
# Typical Water and Fracture Tops From > 4000 fracs

## Fracture Height-Growth Limits in Four Major U.S. Shale Plays (*Fisher, 2011*)

<table>
<thead>
<tr>
<th>Shale</th>
<th>Number of Fracs with Micro-seismic Data</th>
<th>Primary Pay Zone Depth Range</th>
<th>Typical Water Depth and (Deepest)</th>
<th>Typical Distance Between Top of Fracture and Deepest Water</th>
<th>Closest Approach of Top of Frac in Shallowest Pay to Deepest Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnett (TX)</td>
<td>3000+</td>
<td>4700’ to 8000’</td>
<td>500’ (1200’)</td>
<td>4800’</td>
<td>2800’</td>
</tr>
<tr>
<td>Eagle Ford (TX)</td>
<td>300+</td>
<td>8000’ – 13,000’</td>
<td>200’ (400’)</td>
<td>7000’</td>
<td>6000’</td>
</tr>
<tr>
<td>Marcellus (PA)</td>
<td>300+</td>
<td>5000’ to 8500’</td>
<td>600 (1000)</td>
<td>3800’</td>
<td>3800’</td>
</tr>
<tr>
<td>Woodford (OK)</td>
<td>200+</td>
<td>4400’ – 10,000’</td>
<td>200 (600)</td>
<td>7500’</td>
<td>4000’</td>
</tr>
</tbody>
</table>
Drilling, Fracturing and Injection

About 1,000,000 wells drilled in Texas since 1866

Some of longest standing fresh water protection regulations in US.

250,000 producing wells

500,000 fracturing jobs since 1950

48,000 injection & disposal wells

AQUIFERS – Texas Water Development Board
OIL & GAS FIELDS – Bureau of Economic Geology, UT Austin
Treating the Water

Treating the produced water consists on the removal of:
  • Suspended solids,
  • Gas and liquid hydrocarbons,
  • Treating $\text{H}_2\text{S}$ and $\text{CO}_2$ in a few areas
  • Bacteria
Water Recycling
Recycled Water - Quality Standards

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDS at 180°C, mg/l</td>
<td>9,000–16,000</td>
</tr>
<tr>
<td>Turbidity, NTU</td>
<td>0–5</td>
</tr>
<tr>
<td>pH</td>
<td>6.5–8</td>
</tr>
<tr>
<td>Iron, mg/l</td>
<td>1–10</td>
</tr>
<tr>
<td>Chloride, mg/l</td>
<td>5,000–10,000</td>
</tr>
<tr>
<td>Potassium, mg/l</td>
<td>100–500</td>
</tr>
<tr>
<td>Calcium, mg/l</td>
<td>50–250</td>
</tr>
<tr>
<td>Magnesium, mg/l</td>
<td>10–100</td>
</tr>
<tr>
<td>Sodium, mg/l</td>
<td>2,000–5,000</td>
</tr>
<tr>
<td>Boron, mg/l</td>
<td>0–20</td>
</tr>
</tbody>
</table>
Water Processing

Fig. 1—Simplified fracture water process used in the

Oil/Water Separator → Anaerobic Basin → Aeration Basin

Clarifier → Sand Filter → Frac Water to Pipeline Distribution

Fig. 2—Discharge water process used in the Pinedale Anticline field.

Produced Water

Oil/Water Separator → Anaerobic Basin → Aeration Basin → Clarifier

Bioreactor → Membrane Bioreactor → Reverse Osmosis → Boron Ion Exchange

Additional Treatment and Disposal → Clean Water Discharged to Environment

Sand Filter → Frac Water to Pipeline Distribution
Water Processing/Treatment – Electro Coagulation (EC)
## Water Handling Costs

<table>
<thead>
<tr>
<th></th>
<th>Cost, USD/bbl</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acquisition Costs</strong></td>
<td></td>
</tr>
<tr>
<td>Raw Water</td>
<td>0.25–1.75</td>
</tr>
<tr>
<td>Transportation</td>
<td>0.63–5.00</td>
</tr>
<tr>
<td><strong>Disposal Costs</strong></td>
<td></td>
</tr>
<tr>
<td>Transportation</td>
<td>0.63–9.00</td>
</tr>
<tr>
<td>Deep-well Injection</td>
<td>0.50–1.75</td>
</tr>
</tbody>
</table>
Water Treatment Costs

![Graph showing water treatment costs based on salinity and multivalent cations. The graph illustrates that as salinity increases, so do the costs, with different cost ranges for fresh, brackish, saline, and brine water.](https://example.com/graph.png)
Salt Water (Oilfield Brine) Disposal Wells

- Even recycling, which involves some type of evaporation or distillation, can’t give 100% return so disposal of salt water and solids needs to be injected in the disposal wells
- Underground injection in porous rock sealed above and below by unfractured impermeable layers
- Regulated by the Texas Railroad Commission which implements certain rules to protect groundwater
- Construction of multiple layers (3: surface casing, production casing, injection tubing) of casing and cement
- Injection at depths over 1 mi (2mi in the Barnett shale)
- ~ 50000 SWD’s in Texas
- No ground water contamination recorded in Barnett, the state’s largest natural shale gas producing formation (since 1997)
Permian Basin Water Demand & Salt Water Disposal Wells

Fig. 1—An east-west cross section along the southern margin of the Permian Basin shows thicker reservoirs in the Delaware than in the Midland. Operators in the Midland may seek to drill deeper SWD wells into the Ellenburger unit, requiring further capital investment. PW=produced water, HF=hydraulic fracturing, EORI=enhanced oil recovery injection, SWD=saltwater disposal.

Source: Scanlon and Reedy et al. (2017).