Objective of Oil and Gas Wells

The mineral owner and the mineral leasee (i.e. the operator) want a money-making producing oil/gas well with

- A minimum disturbance of the land,
- A lack of bother to the surface owner and nearby residents, and
- No contamination of surface soil and freshwater aquifers
Large Land Drilling Rig

Land Based Drilling Rig
Laterals can be drilled in practically any direction to great lengths
Fracing Equipment
**Idealized Completion of a Horizontal Well**

<table>
<thead>
<tr>
<th>Initial Proposed Completion and Frac Design Goals</th>
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<tbody>
<tr>
<td>★ Fracture half-length capable of draining 80 acres</td>
</tr>
<tr>
<td>★ Fracture height 600-800 ft</td>
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<tr>
<td>★ Fracture width 300-600 ft</td>
</tr>
<tr>
<td>★ Volume: 8,000-12,000 bbls per stage</td>
</tr>
<tr>
<td>★ Proppant: 67.5 lbs per ft (270,000 lbs/stage)</td>
</tr>
<tr>
<td>★ Rate: 65 barrels per minute</td>
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<tr>
<td>★ Fluid: “Hybrid Treatment”</td>
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<tr>
<td>★ Cross-linked fluid</td>
</tr>
<tr>
<td>★ Linear gel</td>
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<tr>
<td>★ Slick water</td>
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</tbody>
</table>
Bottomhole Assembly for Drilling Directional Hole

1. For drilling straight ahead; rotate bit with motor and drill pipe simultaneously.
2. For drilling directionally; orient bit along desired azimuth and rotate with motor only.
Casing & Cement

**Conductor:** needed to circulate drilling mud to the surface without eroding surface sediments below the rig. Cemented to surface.

**Surface Casing:** prevents cave-ins of unconsolidated, weaker, near-surface sediments; protects shallow freshwater sands from contamination; supports BOP’s. Cemented to surface.

**Intermediate Casing:** protects wellbore from sloughing sediments; protects curvature from wear during drilling of horizontal leg. Cemented into surface casing or to the surface.

**Liner with external casing packers:** protects wellbore from sloughing sediments; perforated for hydraulic fracturing and production. Annulus isolated from open hole with packers and liner hanger. No cement.
What is Hydraulic Fracturing?

• One method of stimulating oil & gas well productivity.

• A manufactured fracture placed in the pay zone using hydraulic energy.

• Hydraulic energy is transferred to the formation through a water-based fracturing fluid, causing a crack to appear and propagate.

• Proppant (small sand or ceramic beads) is carried by frac fluid (most common is viscosified water) into the open crack as the fracture is lengthened horizontally and vertically.

• The beads provide a permeable bed in the fracture that 1) withstands compressive earth stress acting to close the fracture and 2) transmits the produced fluids to the wellbore.
Equipment Schematic

- **KCl water**
- Proppant transport
  - Re-circulating blender
  - with turbine meter and densometer
- **High-pressure injection pumps**
- **Liquid**
  - N₂ or CO₂
- **Wellhead**

Diagram notes:
- TM – turbine meter
- D – densometer
- P – metering pump
Proppant

Resin coated sand

Ceramic prop

Natural frac sand

± 1/8"

Healed propped fracture.
Fracturing Fluid

Guar/water gel, viscosity ≈ 30 cp

Cross-linked guar/water gel, viscosity ≈ 300 cp

Desirable Properties
- Stable viscosity and gel strength under reservoir temperature.
- Low fluid loss.
- Low friction.
- Compatible with formation rock and fluids; i.e. not damaging.
- Low cost.

Purpose of a fracturing fluid
- Hydraulically “wedge-open” a crack to initiate and extend the fracture.
- Transport and distribute the proppant along the fracture.
Fracturing Fluid Ingredients

### Typical Shale Fracturing Mixture Makeup
- **90% WATER**
- **9.5% SAND**
- **0.5% CHEMICAL ADDITIVES**

### Typical Chemical Additives Used in Frac Water

<table>
<thead>
<tr>
<th>Compound</th>
<th>Purpose</th>
<th>Common application</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acids</strong></td>
<td>Helps dissolve minerals and initiate fissure in rock (pre-fracture)</td>
<td>Swimming pool cleaner</td>
</tr>
<tr>
<td><strong>Sodium Chloride</strong></td>
<td>Allows a delayed breakdown of the gel polymer chains</td>
<td>Table salt</td>
</tr>
<tr>
<td><strong>Polyacrylamide</strong></td>
<td>Minimizes the friction between fluid and pipe</td>
<td>Water treatment, soil conditioner</td>
</tr>
<tr>
<td><strong>Ethylene Glycol</strong></td>
<td>Prevents scale deposits in the pipe</td>
<td>Automotive anti-freeze, deicing agent, household cleaners</td>
</tr>
<tr>
<td><strong>Borate Salts</strong></td>
<td>Maintains fluid viscosity as temperature increases</td>
<td>Laundry detergent, hand soap, cosmetics</td>
</tr>
<tr>
<td><strong>Sodium/Potassium Carbonate</strong></td>
<td>Maintains effectiveness of other components, such as crosslinkers</td>
<td>Washing soda, detergent, soap, water softener, glass, ceramics</td>
</tr>
<tr>
<td><strong>Glutaraldehyde</strong></td>
<td>Eliminates bacteria in the water</td>
<td>Disinfectant, sterilization of medical and dental equipment</td>
</tr>
<tr>
<td><strong>Guar Gum</strong></td>
<td>Thickens the water to suspend the sand</td>
<td>Thickener in cosmetics, baked goods, ice cream, toothpaste, sauces</td>
</tr>
<tr>
<td><strong>Citric Acid</strong></td>
<td>Prevents precipitation of metal oxides</td>
<td>Food additive; food and beverages; lemon juice</td>
</tr>
<tr>
<td><strong>Isopropanol</strong></td>
<td>Used to increase the viscosity of the fracture fluid</td>
<td>Glass cleaner, antiperspirant, hair coloring</td>
</tr>
</tbody>
</table>

Fracturing Fluid Ingredients

Fracture Fluid for Marcellus Shale
Percent by Weight
(With Proppant)

- Water: 90.6%
- Sand: 8.95%
- Surfactant: 0.08%
- KCL: 0.05%
- Other: 0.44%
- Friction Reducer: 0.08%
- Acid: 0.11%
- Biocide: 0.001%
- pH Adjusting Agent: 0.01%
- Breaker: 0.009%
- Crosslinker: 0.006%
- Iron Control: 0.004%
- Corrosion Inhibitor: 0.001%
Examples of Reservoir Rocks Being Fractured

Naturally fractured shale with vertical fissures.

Producible formations with matrix blocks that have ultra-low permeability are surrounded by nearly impermeable fissures.

Hydraulic fracturing props open a few of a natural fissures, creating passageways for reservoir fluids to flow into the wellbore.

Lenticular sandstones, siltstones & shale
Visualization of the Hydraulic Rock Cracking Process

Similarity with Spitting a Log

The sharp edge of the axe initiates the split. The energy from the axe head lengthens the split and creates width.

When the axe head is moving forward, the log is being split. However, compressive forces from the log create friction that halts the penetration of the axe head.

Long logs are very difficult to split unless an extreme amount of force is applied.
The fracture propagates outwards, upwards, and downwards as it is being created by the pressure of the incompressible fluid.

Fluid loss, due to leak-off into permeable rock, minimizes fracture growth. Also, pressure at the tip decreases due to friction losses as the fracture grows.

Eventually, the volume of frac fluid reaching the tip and the pressures at the leading edge are too low to create further fracture penetration.
Types of Hydraulic Fractures

Mineback photo showing a simple vertical fracture with multiple fracture strands.

Fracture treatments in naturally fractured formations open existing fissures and the result is a stimulated reservoir volume that contains a complex 3-D network of sporadically propped fractures.
Fracing Record

Jones #2A Hydraulic Fracture Record

- Pressure
- Rate
- Concentration

- Breakdown Pressure
- ISIP
- Pad
- Slurry
- Flush
- Fillup

Wellhead Pressure (psig) vs. Time (minutes)
Can a Vertical Fracture Intersect a Shallow Fresh Water Aquifer?

• No.

• Evidence
  ✓ Well construction
  ✓ Microseismic measurements
  ✓ Tiltmeter data
  ✓ RA tracer surveys
  ✓ Volumetric calculations
  ✓ Pressure recordings during treatment
Wellbore Diagram

**Stimulation:**
- 20 individual frac treatments
- Transverse fractures
- Each approximately 70,000 gal frac fluid
- 67,000 lbs proppant
- 74,000 gal slurry
- 30 BPM @ 5,300 psi

**Totals**
- 1,400,000 gal frac fluid
- 1,340,000 lbs proppant
Assuming that fresh water aquifers in the vicinity of the well are found at about 1,000' below ground level, then the top of the fracture is located roughly 6,900' below the aquifer.
Microseismic Sections

Fig. 2—Barnett shale measured fracture heights sorted by depth and compared to aquifers.
Proppants, coated with short half-life radioactive material, placed in hydraulic fractures can be located with gamma ray measurements. GR logs identify the position of the proppant behind the casing.

These logs show where the fracture exited the wellbore and the near-wellbore height of the propped fracture.

Similar logs can be made by measuring wellbore temperature after the fracturing treatment is concluded.
Checks While Performing Frac Treatment

Plot is made in real time to monitor the performance of the treatment.

If unstable height growth is shown, the treatment is terminated immediately.
Treating & Recycling Produced Water

- Total volumes of water required for drilling and fracturing a horizontal well average 20,000 barrels in the Williston Basin to over 250,000 barrels in other basins.

- Water is expensive to handle. Published transportation and disposal costs range from $2 to $14 per barrel.

- Roughly 20 to 40% of frac water is recovered following the treatment.

- Once fresh water becomes oilfield waste and is disposed below the fresh water table, it is permanently removed from the fresh water cycle.

- Strong reasons to recycle oilfield water
  - Conservation
  - Economic
  - Environmental
Treating & Recycling Produced Water

Common methods of treating water

1. Thermal, create water vapor by evaporation or distillation.
2. Physical
   • Particle filtration
   • Membrane filtration
     ✓ Ultrafiltration, removes colloidal sized particles
     ✓ Nanofiltration, removes multivalent cations
     ✓ Reverse osmosis, removes virtually any ion
3. Chemical
   • Liquid chemicals treatments
   • Oxidative and electrochemical processes
     ✓ ClO$_2$
     ✓ O$_3$
     ✓ Electrochemical precipitation
Treating & Recycling Produced Water

Benefits of onsite water treatment

1. Minimizes truck traffic and emissions.
2. Reduces dependency on fresh water for frac treatments.

Hydrozonix LLC is expanding its fleet of EF80™ treatment units to service fracturing operations in the Permian Basin and the Marcellus Shale, with the company planning to build two units each quarter over the next two years, depending on market demand. Each EF80 unit can treat 80 bbl/minute during fracturing and post-frac flow back. The systems use the patented Ozonix™ oxidation process that incorporates ozone, hydrodynamic cavitation, acoustic cavitation, and electro-chemistry for microbial control and scale inhibition.

This mobile water treatment and recycling unit is shown in operation at a site in the Barnett Shale. The NOMAD™ skid is based on mechanical vapor recompression, and is constructed and operated by Fountain Quail Water Management. Each skid recovers up to 2,000 bbl/d of demineralized water from brines.