Shale Development and Hydraulic Fracturing
or
Frac’ing (Fracking) – What is it?

Dr. Will Fleckenstein, PE
Colorado School of Mines
Who is involved in discussions on “Fracking”? 

Dr. Frackenstein
The shale plays are widespread
Occur anywhere conventional production exists
How do you drill and complete these shales?
United States Horizontal Rotary Rig Count

1000% Increase in horizontal rigs

Source: Baker Hughes Inc., Bloomberg LP
Haynesville Results

Production is dropping

Haynesville Natural gas production
million cubic feet/day

Gas -120
million cubic feet/day
month over month

Source: EIA, October 2013
Natural Gas Cheap Compared to Oil, Driven by Shale Gas Production

The shale plays are widely separated, with different geologic properties, but they have one uniform effect:

They are driving down natural gas prices in the US.
Marcellus Well Results
Results continue to improve

Marcellus
Natural gas production
million cubic feet/day

Gas +408
million cubic feet/day
month over month

Source: EIA, October 2013
Marcellus Well Results
Wells are getting **better**

Marcellus
New-well gas production per rig

<table>
<thead>
<tr>
<th>thousand cubic feet/day</th>
<th>Rig count</th>
</tr>
</thead>
<tbody>
<tr>
<td>6,000</td>
<td>160</td>
</tr>
<tr>
<td>4,800</td>
<td>140</td>
</tr>
<tr>
<td>3,600</td>
<td>120</td>
</tr>
<tr>
<td>2,400</td>
<td>100</td>
</tr>
<tr>
<td>1,200</td>
<td>80</td>
</tr>
</tbody>
</table>

- **new-well gas production per rig**
- **rig count**
What about Unconventional Oil Production?
- Bakken Production in North Dakota
Is this Affecting US Oil Production?
Drilling and Stimulating a Horizontal Shale Well

Horizontal Well

Vertical Well

Fracture stimulation

1-4000 m deep

300-3000 m long
Each horizontal replaces many vertical wells
1. Drilling
   • Modern horizontal drilling began in 1990, with the widespread acceptance of MWD (Measurement While Drilling) to steer the wellbore horizontally.
   • This allowed the experimentation in the Barnett Shale by George Mitchell, resulting in horizontal laterals, coupled with multi-stage fracturing, to develop shales
   • Pad drilling

2. Casing
   • The curvature of wellbore meant that the casing had to curve also, resulting in connections designed to withstand the torque and drag of a horizontal well
   • The casing many times has to be rotated to bottom, driving the acceptance of top drives on rigs, and special tools to facilitate this rotation

3. Cementing and Isolation
   • Special tools and cements were developed to isolate and cement these wellbores, including expandable liner hangers, inflatable and “swellable” packers.
How do we drill a horizontal well?

Change direction by rotating bit with a downhole motor, or a rotary steerable system – deflect the bit

- Controlled curvature
- Controlled direction
- Geo-steering

“PDC” Bits
How do we drill a horizontal well?

Drill straight by rotating the drill string, so that the bit is never pointed in a single direction.

- Maintain direction of the bit
- Rotary steerable or mud motor system
- Drill string rotation may or may not be necessary
Why Stimulate?

**Number of Days for a Methane Molecule to Travel 1 meter**

- **PERMEABILITY**
  - 1 microdarcy
  - 100 nanodarcies
  - 10 nanodarcies
  - 1 nanodarcy

- **# DAYS**
  - 10
  - 100
  - 1,000
  - 10,000

Courtesy Ken Mahrer, Apex
What Should be Done Prior to Horizontal Drilling?

1. Establish a baseline of potential contaminants in aquifers
   - Natural gas
   - Natural dissolved solids
   - Identification of pre-existing pollution

2. Identify barriers to hydraulic frac growth in the reservoir

3. Construct a reservoir model, including mechanical properties of rocks, identification of natural fractures, amount and type of hydrocarbons

4. Water sources and disposal

5. Logistics
Drilling rigs are very large and result in 150 direct and indirect jobs per rig.

The drilling rig needs good roads, bridges etc. to move. The best rig move is to not move very far, but to drill multiple wells from 1 pad (pad drilling).

Proper well siting allows multiple wells to be drilled from the same location.

The drilling rig “walks” from well to the next, minimizing time, costs and allowing the least surface disruption.

Colorado wellsite
Six complicated wells drilled from a single surface location in California amid other wells
Typical Well Construction

- Conductor pipe
- Surface casing
- Intermediate casing
- Production casing

Legend:
- Steel casing or pipe
- Cement
Primary Cementing Objectives

- Anchor the casing
- Protection casing against corrosion and erosion
- Support borehole walls

- **Zonal Isolation**
1. The hole is drilled for the first string of casing.
2. The casing is then cemented in the wellbore to the surface.

Surface Casing Purpose
1. Protect Surface water
2. Anchor BOPE
3. Support casing strings
4. Well Control

Cementing Process
Colorado Example
Regulations Governing Surface Casing

e. Surface casing where subsurface conditions are unknown. In areas where pressure and formations are unknown, sufficient surface casing shall be run to reach a depth below all known or reasonably estimated utilizable domestic fresh water levels and to prevent blowouts or uncontrolled flows and shall be of sufficient size to permit the use of an intermediate string or strings of casings.

Surface casing shall be set in or through an impervious formation and shall be cemented by pump and plug or displacement or other approved method with sufficient cement to fill the annulus to the top of the hole, all in accordance with reasonable requirements of the Director.

Cementing Difficulties

Pipe may be not centered

Hole may be washed out
What can we see?

- Tubing hanger
- Tubing
- Production Casing
- Casing hanger
- Casing head
- Cement
- Surface Casing
3 Key Elements of Horizontal Multistage Fracturing

1. Water fracs
2. Microseismic Mapping
3. Multiple Stages
Fracturing animation
Sliding Sleeve with Isolation Packers

Completion string, consisting of sliding sleeves and packers, is run into well.

Packers are exposed to hydrocarbons and swells to create seal with wellbore.

First zone is stimulated.

Ball is dropped and second zone is stimulated.

Larger diameter ball is dropped and third zone is stimulated.

Process can be repeated for up to >30 stages

Courtesy Ken Mahrer, Apex
Horizontal Completions
Frac Baffles or Frac Sleeves

Diversion with Expandable Packers
Sleeves are actuated with balls
Fracturing Materials
Waterfracs

- Slickwater (water with friction reducer)
- Low sand concentrations
- 1-5 million gallons per well
- Low fluid loss
Water Frac Fluids

A FLUID SITUATION:
TYPICAL SOLUTION* USED IN HYDRAULIC FRACTURING

0.49% ADDITIVES*

- Potassium chloride 0.06%
- Ethylene glycol 0.043%
- Sodium/Potassium carbonate 0.011%
- Sodium chloride 0.01%
- Borate salts 0.007%
- Citric acid 0.004%
- N,N-dimethyl formamide 0.002%
- Glutaraldehyde 0.001%
- Acid 0.123%
- Isopropanol 0.085%
- Petroleum distillate 0.088%
- Guar gum/Hydroxyethyl cellulose 0.056%
Geologic Considerations
What is a Shale?

Now we are trying to produce this shale that is ~1000 times less permeable than tight sands.

And a million times less permeable than conventional Sands.

“milliDarcy”
~0.1 to 10,000 mD

“microDarcy”
~0.001 to 0.1 mD

“nanoDarcy”
~0.000,010 to 0.001 mD

Courtesy, Mike Vincent, consultant
What is a **Desirable** Gas Shale?

“Brittle Shale” (Complex Fracturing):
- low Poisson’s Ratio & high Young’s Modulus
- moderate Clay content : < 40%
- bounded by frac barriers
- heterogeneity

Gas-in-place (Bcf per square mile) :
- 30 is good, 150 is better

Permeability greater than 100 nanodarcies

Porosity: > 4%

TOC: >2% (1-3% is typical, 5-15% is great)

Moderate Water Saturation < 45%

Thick zone : >100 ft

Courtesy, Halliburton
Fracture Networks Are a Key
What about Vertical Heterogeneity?

- Shales
- Silty Shales
- Mudstones
- Silt Stones
- Sandy laminations

What a mess!!
But they all may produce!!!
Most induced fractures are vertical and are driven toward lower horizontal stress.

For instance a fracture growing in A4 will have a difficult time breaking across the shale above, which is higher stress (in red), and instead will move to the lower stress and stay in zone.

To predict where the fracture goes, you must predict what the stresses are, and for this, you need to know what the rock properties are.

The rock properties, such as Poisson’s ratio and Young’s Modulus, must be determined from cores or logs.
Horizontal Completion Technology
Why not just a horizontal well?

- 100 ft Vertical well: 160 ft² of contact
- 2,000 ft Horizontal well: 3,207 ft² of contact (20 x vertical)
- 2,000 ft Horizontal well with 10 x 150 ft fractures: 153,207 ft² of contact (957 x vertical, 48 x horizontal)
Horizontal Completions (Complex Fracturing)
Microseismic
Microseismic Improves Diagnostics

Microseismic

- Maps the fracture growth
- Identifies azimuth
- Measures frack distance from aquifer
- Requires observation well
Micro-Seismic Data Processing

3-D Velocity Grid

P-wave moveout

Wellbore

Courtesy Ken Mahrer, Apex
Barnett Microseismic
Fracture Heights vs. Deepest Aquifer
Marcellus Microseismic Fracture Heights vs. Deepest Aquifer
Shales May Have Gas, Wet Gas, or Oil

Eagleford Trend, South Texas (Source – EOG)
Green Completions

Green completions take place during the clean-up stage of the completion, after a well has been “fracked.”

The clean-up involves removing the water necessary to frack the well. During this flow back, natural gas is produced with the water.

What makes the well completion “green,” or environmentally friendly, is that the gas is separated from the water and placed in a pipeline instead of being released to the atmosphere.

Green completions have been Devon’s standard practice in the Barnett Shale since 2004.

Devon has reduced methane emissions by more than 25 billion cubic feet in the Barnett Shale area of north Texas during 2,000 green completions.
Green Completions

First, a sand separator (shown at right in this photo) filters out any sand, sending it through a 2-inch pipe into the disposal tank. That filtering leaves a mixture of natural gas and water.

The second piece of equipment (in the left side of this photo) separates the water, which then reunites with the sand in the disposal tank.

The gas, meanwhile, is diverted into a separate pipe and eventually is sent by pipeline to a processing plant.

The key to the green completion is that a pipeline must be available for immediate usage.
Thank you for your attention

Questions?