SPE 133456
Thirty Years of Gas Shale Fracturing: What Have We Learned?

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Observations

• No two shales alike. They vary aerially, vertically & along wellbore.
• Shale “fabric” differences, in-situ stresses and geologic variances often require stimulation changes.
• First need - Identify critical data set
• Second need – never stop learning about the shale.
Shale Technologies

Enabling
- Slick Water Fracs & Hybrid Fracs
- Horizontal Wells
- Multi-stage Fracs
- “Simo” Fracturing

Optimizing
- Critical Data Set
- Frac Complexity
- Special Materials
- Flowback
- Water Management
- Production

What are the technology Gaps?
Next generation advances?
“Critical” Factors for Shale

Critical Need
- Gas-In-Place
- Adequate Matrix Permeability

Manageable Need
- Adequate Water Management
- Adsorbed Gas

Important Need
- Natural Fracs
- Pressure
- Maturation
- Net Thickness
- Diagenesis
- Mineralogy
- Brittleness
- Free Gas
- Depth
- Present Gas Production
- Organic Richness

Significant Need
- Understanding Stresses
- Understanding Geological Hazards
- Understanding Shale Sensitivity
- Kerogen Type
- Frac Barriers Present
Thermogenic or Biogenic Gas

Measured Antrim values

Low maturity shale: Different risk factors! If high dry gas content and low maturity, it is likely biogenic gas

Dan Jarvie, Humble Geochemical, 2004
Maps - Find the Sweet Spot!

- Mapping a “sweet spot” in a shale play reduces the risk of economic failure.
  - Critical Variables?
  - Pore Pressure
  - Gas in Place
  - Maturation
  - Depth of Burial
  - Natural Fractures
  - Shale Thickness
  - Pore or Reservoir Pressure
  - Structures?
  - Production
Inverse correlation of BTU content to vitrinite reflectance

Discounts the presence of nonhydrocarbon gases that would alter the BTU prediction i.e., do not use if greater than 2% CO2 or N2 are present

Dan Jarvie, Humble Geophysical, 2004
Critical Factors vs. Critical Data Set

• Factors describe the shale to be evaluated – not the whole play.

• Data sets include:
  
  – How to get the most accurate & representative data for the specific shale.
  
  – Knowledge of what operations are needed to optimize production.
  
  – “Must have data” includes environmental concerns and resolutions.
Examples - Natural Fractures

- Natural pathways.
- Open at 50 to 60% of rock frac pressure.
- Open by low viscosity fluid invasion.
- Difficult to prop.
- Dominates Permeability
Fissures & Natural Fractures
Opening natural fractures takes ~ 50 to 60% of the stress to break the rock.
Natural Fractures – Primary and Secondary

Shale outcrop in stream bed. Note the primary (blue) and secondary (yellow) natural fractures. A third natural frac set can be seen at the bottom of the picture.

Gary Lash – SUNY, AAPG
And, in the matrix.....

- Interconnected porosity is in matrix too. Look at alteration from diagenesis & maturation.
- Porosity in organics may dominate inter-granular porosity
Shale Modulus? – a Good Indicator of Performance?

- Gas shales group w/ tight sand clastics.
- Non-productive shales have a low static modulus and scattered dynamic modulus.

Dynamic to Static Young’s Modulus Correlation

(Britt, et. al., 2009)
Completions

• Maximize frac contact with shale.
  – Wellbore orientation
  – Wellbore length
  – Toe up or down?

• Number of Frac Stages
  – How to place: by average distance or gas shows?
  – Spacing, number, holes?
  – Hydraulic diversion?
Fracturing Fluids and Methods

- Fluid Types
  - Slick water fracs
  - Gels and cross-linked gels
  - Foams
  - Gas (both gas and dense phase)
  - Liquefied petroleum
  - Hybrids (mixtures and separate stages)
  - Others (explosive, clay reactive fluids, acid, etc.)
Shale Fracs – What is Different?

• Slickwater is predominant fluid, but not in every case.
• Hybrid Fracs gaining popularity
• Intersection of multiple natural fractures is maximized.
• Large jobs at very high rates appear to work best.
  – 1 to 6+ million lb or 0.4 to 3 million kg proppant
  – 2 to 12+ million gal. or 46,000 m³ of water
Technology Application & Progression of Shale Development

Horizontal Wells, Multistage Fracturing, Slick Water Fracturing
Step-rate increases
All tested in Devonian shale 10 years before Barnett.

The adaptation that made them work in Barnett was large volume fracs & very high rates.

SPE 16410, 26925, 21264, 19090, 16681, 17759

Re-Fracs – Work Great in Shale

Re-Frac methods are suited to the shale & to specific operation.

Most re-fracs have been on verticals, but technology improvements have shown promise on multi-frac horizontal wells.

Source: Cipolla, et. al., SPE 124843 modified from Warpiniski, et. al., SPE 95668.
Refrac Results

- Shale wells respond more consistently to refracs than other pay types. Probably an 80 to 90% success rate on targeted shale refracs vs. 30 to 40% on sandstone refracs.
- Re-fracs on early vertical shale wells generates a 50 to 60% increase in IP and 50 to 75% in EUR.
- Horizontal well improvement less than in verticals but still economic.
Can Fracture Complexity in Shales Be Proved?

Complexity (networking) increases as natural fractures are opened and connected by hydraulic fracturing.
Starting Point.....

Initial – high rate, tracers & micro-seismic. Follow up?
Next – shorten the frac and make it wider.......

> 20% of M-S events below pay 500 BWPD

$W/X_f = 0.3$
Single Fracs – Reaching too Far?

$W/X_f = 0.7$
Next Step – Optimize the Rate

Sequential Fracs, rate by M-S activity, $X_f$ not yet modified by sand slugs
<5% of points below Barnett
Well made ~ <50 bwpd
Zipper Frac - generally good complex fracture coverage.

Sequential Fracs – Proof of Control

Wellbore at 90 degrees to the frac direction - does secondary frac ruin isolation?

Wellbore Orientation?

60 degrees

FCI = $W/X_f = 2$
Frac Initiation Points

The fractures may start out at the high energy borehole by following fractures created during drilling. When the fractures reach beyond the wellbore, the formation in situ stresses begin to be exerted and the frac can turn to match the current stresses. Influences such as prior fracturing may store new stresses in the rock. Secondary fractures may prevail on the frac direction.

Above – Image logs of three wellbores with different stresses. Right – a new fracture direction established after leaving the wellbore during a refrac.
Stresses Change During Fracturing

Displacement field in the earth around a vertically oriented hydraulic fracture, showing induced surface and downhole tilt vector directions. Siebrits, 2000
How much of the frac is propped?

The upper, unpropped part of the fracture does not have high flow capacity, but is still far more permeable than the shale matrix.

The unpropped area does support sufficient vertical permeability to flow gas in very low permeability formations, thus can be a contributing part of the fracture as it transfers gas downward to the propped area.

If conductivity in the unpropped section is maintained (typically a function of brittleness, mineralogy and local stresses), then slickwater fracturing is an option.

If the fracture heals, as in high ductility formations or the formation is extremely thick, gel fracs must be considered to gain more propped coverage.
Frac Technology Gaps

• Biggest Apparent Problem is lack of stable flow paths – conductivity.

• Movement toward hybrid fracs:
  – Slickwater first, then gel or x-link gel
  – Gas energy may help – or not.

• Limits? - Rate, Volume, Stage, Sweeps
Production Styles – Varies with source.

Type Curve (Well Performance) for three distinctly different unconventional reservoirs.
Production Variation

Reserves Issues – Current and New SEC Rules
Variation in Well Performance

Barnett Shale
Northeast Wise County

- Wide range of performance trends for wells in close proximity
- EURs range from 0.3 Bcf to 3.6 Bcf
  - Average EUR is 1.5 Bcf
- There may not be a ‘typical’ well

Scott Rees, Hart DUG Conference, October 19, 2009, Pittsburgh
Multi-Well Pads
Develop by Vertical or Horizontal Wells? 4 sq. mile area (2560 acres)

Vertical wells - 64 vertical wells on 2 acre pads use 128 acres of land, about 26 miles of roads, 26 miles of pipelines, plus 4 to 8 facility pads to effectively capture the gas reserves.

Horizontal wells – 16 horiz. wells from 1 pad of 6 acres, with 2 miles of roads, 2 miles of pipeline and one facility on the same pad as the wells.

Horizontal well advantages:
• Less land used & placement choices,
• Fewer roads and pipelines,
• Less traffic,
• Less dust,
• Less urban & wildlife disturbance,
• Less air pollution.
• All wells penetrate the ground in the same area – can be easily monitored
Water Management

• Large volumes of fresh water not required.
• Recycling frac & produced waters
• Higher salinity sources are now usable.
• Chemical Management is Essential
  – Biocides under the microscope
    • Greener (bio-degradeable and no bioaccumulation)
  – Lower vol. of chemicals (what’s really needed?)
Brackish Water Source for Fracs

- High perm sand w/ 35,000 ppm, sour (H₂S) brine is present ~ 2,000’ above gas shale target zone.
- Brine can be supplied at high rate to the treating facility for sweetening and then to the frac spread for pumping.
- Flowback water is cleaned and re-injected.
- Advantages:
  - Fresh water use is cut to a minimum.
  - High Cl⁻ brine eliminates or reduces many chemicals
  - Surface storage of frac brine is <<5% of job volume.
  - Higher salinity brine stabilizes shale?
  - The hot water from the reservoir eliminates very expensive water heating need and eliminates air emissions from the heater
  - Cheaper than fresh water for development of multi-well pads
  - Lowest Environmental Impact and Smallest Foot Print
Getting away from fresh water use – Saline Water Supply Schematic

- **77-K Non Potable Water Source Well**
- **67-K Non Potable Water Source Well**
- **Mercaptan Scavenger & PH Buffer**
- **Treated Non Potable Source Water for Fracture Stimulations**
- **ACL d-70-K Well Pad**
- **ACL d-52-L Well Pad**
- **90-J Non Potable Water Disposal Well**
- **Debolt Reservoir (ASR) Non-Potable Aquifer Storage Reservoir**
- **Fresh Water Lake**
- **Borrow Pits For Freshwater Storage Only**
- **Fresh Water Make-Up**
- **C-67-K/94-O-08 Etsho Compressor Station & Water Plant Site**
- **Separator Vessels & Treated Water Storage Tanks**
- **67-K Plant Inlet Separator**
- **Produced Shale Gas & Fracture Stimulation Flowback Water**
- **Produced Natural Gas to Spectra Sales Tie-In**
- **Produced Fracture Stimulation Flowback Water**

* Water Recycle Line, Stimulation Flowback Water Compatibility Under Review

* Closed system, no storage of treated water in un-lined burrow pits.
Deciphering Chemical Tracer Results in Multi-Fractured Well Backflow in Shales: A Framework for Optimizing Fracture Design and Application

George King – Apache Corporation
Dick Leonard - Protechnics
Using All The Data to Help Understand The Frac Behavior.

FCI = W/X₁ = 2
Conclusions from 30+ yrs of publications
(and a bit of application experience)

• ~ 400 papers reviewed, 270 quoted
• Shale gas is now a major asset.
• IP and EUR increasing with time and understanding of the shale.
• Shale fracturing continues to evolve – hybrid fracs now common.
• Optimizing parameters of shale frac backflow not yet understood.
Shale Development Observations

• Spend money on early science – know maturity, barriers, natural fracture information, stresses, thickness, stimulation methods, geosciences, etc.
• Expect a learning curve (expenses decrease and IP & EUR increase) for each operation.
• Use technology during completions, stimulation and flowback to understand how to improve.
• Technology is a necessary “enabler” in shale formations.
Questions?