Key Considerations for Hydraulic Fracturing of Gas Shales

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Introduction

• Why Unconventional Gas Reservoirs need to be Hydraulically Fractured
• The importance of complex hydraulic fracture geometry
• The Hydraulic Fracturing Process described
• Fracturing Materials
• What Can We Control During a Fracture Treatment?
• Why cause and effect with respect to production are not always obvious
Why We Fracture Shale Gas Wells

- Sealed natural fracture system shale wells, as they occur naturally, will not produce economic quantities of gas.
  - Mineralized and sealed natural fracture systems
  - Implication of nano-Darcy matrix permeability on molecular travel rate
  - Goal is to give every gas molecule a high-speed path to the well-bore
  - The hydraulic fracturing process creates not only tensile fractures, but also shears existing fractures in the target.
Shale Gas

- Shale Gas plays
  - Typically mudstones of varying mineralogy
  - Typically sealed natural fracture systems
SEM Comparison

- **apatite**
- **framboidal**
- **pyrite**

- **bladed chlorite**
- **calcite**

**Image Specifications:**
- **Acc. V:** 20.00 kV
- **Spot:** 3.3
- **Magn.:** 1000x
- **Det:** BSE
- **WD:** 9.7
- **Scale:** 20 µm

**Image Specifications (Bottom Right):**
- **Acc. V:** 20.00 kV
- **Spot:** 4.0
- **Magn.:** 1000x
- **Det:** BSE
- **WD:** 10.6
- **Scale:** 20 µm

**Image Specifications (Top Left):**
- **Acc. V:** 20.00 kV
- **Spot:** 3.3
- **Magn.:** 1000x
- **Det:** BSE
- **WD:** 9.7
- **Scale:** 20 µm

**Image Specifications (Bottom Left):**
- **Acc. V:** 25.00 kV
- **Magn.:** X1000
- **WD:** 0832
- **Scale:** 10.0 µm
Mobility Comparison

\[ q \approx \frac{kh(P_{res} - P_{wf})}{u[\ln(r_e/r_w) + S]} \]

![Graph showing mobility comparison](image)
Three Data Points

• Gas molecule movement in shale on the order of 10 feet in the lifetime of a well - Dr. Mohan Kelcar, University of Tulsa.

• Gas molecule movement of about a meter/year modeled by Nexen’s Unconventional Team, presented at Global Gas Shales Summit, Warsaw, Poland.

• Gas molecule movement of a few feet/year modeled by Dr. Chunlou Li, Shale Gas Technology Group.
Begin With the End in Mind?

• Think about the frac before planning where to land the lateral.
• What frac fluid will be used?
  – How effectively can it transport proppant above the level of the horizontal in thick pay zones?
• Is there a good lower frac barrier?
• An effective set of propped fractures and sheared fractures is actually what you are buying in gas shales.
  – How much embedment is expected?
  – Is the proppant strong enough?
  – Will the proppant retain strength over the long term?
  – What is the maximum length of lateral that can be placed into the formation and effectively cleaned up after fracturing?
Classic Bi-Wing Fracture

\[ \text{SH}_{\text{max}} \quad \text{Sh}_{\text{min}} \quad Sv \]
Horizontal Wellbores End Member Fracture Geometries

Transverse

Longitudinal

$\sigma_{h,\text{max}}$

$\sigma_{h,\text{min}}$
Complex Hydraulic Fracturing

- Requirement for sealed natural fracture shale gas systems
The Hydraulic Fracturing Process
Pump Pad, Slurry, & Flush (Repeat as Necessary), and Recover

• A fracturing treatment operation begins by rigging up a high pressure steel treating or flow line from special high-pressure fracturing pumps to the well and pressure-testing the equipment for safety.

• The next step is to inject a large volume of special fluid(s) into a prospective producing formation at an injection rate that will place sufficient stress on the rock to cause the rock to physically split (fracture) in one or more places. This initial volume of fluid is termed the “Pad” and typically comprises 20% of total fluid volume.
The Hydraulic Fracturing Process

• The Pad fluid is pumped to create enough fracture width to accept proppant particles. Proppant is typically comprised of size-graded, rounded and nearly spherical white sand, but may also be man-made particles.

• Proppant particles are mixed into additional fracturing fluid and the resulting slurry is pumped into the reservoir, propping open the created fracture(s) so that they will remain open and permeable after pump pressure is relieved.
The Hydraulic Fracturing Process

• At the end of placing the slurry, a tubular volume of clean “Flush” fluid is pumped to clear tubulars of proppant and the pumps are shut down.
• Well pressure is then bled off to allow the fracture(s) to close on the proppant.
• The final step in a fracturing treatment is to recover the injected fluid by flowing or lifting the well (load recovery.)
Functions of the Fracturing Fluid

• **Transmit energy** to the formation to split the rock
  – Pressure and rate

• **Transport proppant**
  – Through tubulars, completion, near-wellbore, fracture

• Also needs to be:
  – **Compatible** with formation minerals and fluids
  – **Easy to recover**
Fracturing Fluid = Base Fluid + Additives + Proppant
Basic Fracturing Fluid Materials (1)

- **Base Fluids** (make-up fluids)
  - Water, Oil
- **Energizing Gases** – used to aid in fracturing fluid recovery
  - CO₂ or N₂ or both
- **Gelling Agents** - Viscosifiers used to thicken fracturing fluids (1’s to 10’s of centipoise) to improve fluid efficiency and proppant transport.
  - Guar Gum or modified Guar Gum
- **Crosslinkers** – Used to super-thicken fracturing fluids (100’s to 1000’s of centipoise)
Basic Fracturing Fluid Materials (2)

- **Friction Reducers** – Used in Slick Water Fracs to reduce friction losses in pipe while injecting fracturing fluids
- **Breakers** – used to reduce viscosity of fracturing fluids after the treatment to allow fluids to more easily flow out of the formation for recovery
- **Surfactants and Non-emulsifiers**
  - Surfactants reduce surface tension – aid in fluid recovery
  - Non-emulsifiers prevent treatment fluid and reservoir liquids from emulsifying
Basic Fracturing Fluid Materials (3)

- **Temporary Clay Control Agents** – prevent clay swelling and minimize migration of clay fines
  - 1 – 7% KCl
  - TMAC
- **Biocides** – kill bacteria in fracturing fluid make-up waters
  - Used to minimize souring of reservoirs resulting from injection of contaminated surface water
  - Used to prevent bacteria in make-up water from destroying gelling agents before the treatment can be pumped
- **Gelling Agent** = Bug Food
Water-Based (Aqueous) Fracturing Fluid Systems

- Polymer systems
  - Crosslinked
    - High or low pH
    - Instant or delayed crosslink
  - Linear systems
    - High gel loading
    - Slickwater
- Non-polymer systems
  - Viscoelastic surfactants
Crosslinked Polymer
Hydrocarbon-Based (Non-Aqueous) Systems

• **Oil-based systems**
  – Any non-polar liquid hydrocarbon
  – Crosslinked

• **Emulsified systems**
  – Two parts linear gel to one part oil
  – Oil-external emulsion

• **Methanol systems**
  – Methanol/water mixes or 100% methanol
Energized vs Non-Energized Fracturing Fluids

- Energized fluids are fracturing fluids mixed with compressed gas, usually either CO$_2$ or N$_2$
  - Advantages
    - Provide a substantial portion of the energy required to recover the fluid
    - Places much less water on water-sensitive formations
  - Disadvantages
    - Not possible to place high proppant concentrations in the fracture
Fracturing Fluid Selection

See Fig 7-53, Page 272
Types of Proppant

- Ottawa Frac Sand
- LiteProp™ 108 ULWP
- Low Density Ceramic
- Brown Frac Sand
- Resin-Coated Sand
- Sintered Bauxite

See Section 8-8 for a full discussion on proppant selection.
What Do We Want The Proppant To Do?

• Keep the fracture *Propped Open* throughout the created fracture area
  – Across the length and height of the interval

• Provide sufficient *conductivity contrast* to accelerate flow to the wellbore
  – Provide permeable pathway
  – Maintain fracture width
Proppant Selection Considerations

- Proppant permeability is a key design parameter dependent upon:
  - Size distribution
  - Closure stress
  - Damage, i.e. treating fluid residuals
- Proppant permeability can change over the life of the well
  - Non-darcy flow
  - Production damage (scale, fines, etc.)
Proppant Selection Considerations

• **Sizing** - larger proppant provides greater permeability but can be more difficult to place
  – Larger proppants create larger open areas for flow
  – Bridging
    • Perforation diameter should be 6 times larger than proppant diameter
    • Hydraulic fracture width should be 3 times larger than proppant diameter
  – Settling
    • Rate of setting increases proportional to \((\text{diameter})^2\)
Proppant Application Ranges
20/40, 2 lb/ft² - Minimum 500 md-ft

Closure Stress, psi
Proppant embedment ranges from minimal in “hard formations” to typically as much a \( \frac{1}{2} \) grain diameter in “soft formations”

Damage from embedment is two-fold: width loss and fines
Fracturing Materials Philosophy

• Fracturing materials are essentially tools in a toolbox
• Each material has its application range
  – Applying fracturing materials outside of their application ranges is likely to lead to catastrophe
• No material is “universal”, i.e., no one fracturing material is appropriate for every reservoir
Fracturing equipment (frac fleet or frac spread)

- **Blender** mixes fluids, chemicals and proppants, and increases pressure of the mixture so it is ready to enter the high-pressure frac pumps
- **Chem-add** unit delivers precisely metered amounts of chemical additives to the blender
- **Frac equipment pumps** the fracturing fluid / slurry into the well at pressures and injection rates sufficient to split or fracture the formation
- **Sand Truck or Sand King** delivers proppant to location and delivers it to the blender for mixing with the fracturing fluid

- **Injection rate and surface treating pressure**
  - Frac pump “power” is rated in “**hydraulic horsepower**,” calculated as injection rate (bpm) * Pressure (psi) / 40.8
  - 80 bpm * 10,000 psi / 40.8 = 19,608 HHP
  - Requires minimum of 20, 1,000 HHP pumps or 10, 2,000 HHP pumps, etc.
Modern Frac Fleet on Location
What Can We Really Control In the Fracturing Process?

- Proppant properties & quantity(ies)
- Proppant distribution?
  - Location in 3-D space and propped fracture width distribution
- Fluid rheology(ies) and volume(s)
- Injection point(s) – sometimes…
- Injection rate and rate of change
- Flowback rate

- What about how the rock cracks?
Fracturing Challenges in Unconventional Gas Reservoirs

- **Simple or complex** fracture geometry?
- Hydraulic fracture **height, length, width** or **reservoir volume accessed**?
- Fracture **azimuth**?
- Geohazards?
  - Faults
  - Karsts
  - Wet zones
- Where did the frac go and what did it touch (or not)?
- Where was the proppant placed and how was it distributed?
- Which zones cleaned up the frac fluid and are productive?
Post Fracture Treatment Monitoring Methods

• Conventional Temperature and Tracer Surveys
  – Immediate or near-immediate post-frac
  – Data pertains only to immediate well-bore vicinity
  – Requires post-treatment logging
  – Fluids and proppant can be traced
• Distributed Temperature Sensing (DTS)
  – Especially useful for cleanup studies
• Production Logging
  – Spinner surveys
  – Requires logging well after fracture fluid cleanup
• Microseismic Monitoring
  – During the fracture treatment
  – Near real-time
  – May be used for post-treatment analysis and for near real-time treatment management
Is the frac staying in zone vertically?

*Image courtesy Steve Sadoskas, Baker Microseismic*
Microseismic Monitoring

What is the induced fracture azimuth?
Is the frac simple or complex?
Is the frac providing desired areal coverage?

Image courtesy Steve Sadoskas, Baker Microseismic
Barnett Play Overview
Brnt Shale Production Time Line - Evolution

- Small energized fracs
- Cross link MHF
- First Horiz well
- μ-seismic
- SWF

Brnt Update May 2009
11494 Samples for 11782 Wells

COMP_DATE
Treatment Evolution Horiz Brnt Wells
Treatment Evolution – Prop Qty Increase
Log10 6 Mo Gas Cum Hor Wells
Critical Production Drivers: Well Architecture

- Vertical vs horizontal wells
- Horizontal length
- Azimuth deviation from Shmin
- Well attitude: toe up vs toe down
Critical Production Drivers: Well Architecture
Effect of Length, Horizontal Wells
Gross Effect of Drift Angle

2619 Samples for 3206 Wells

- Production Max Gas Comp: Highest Rate of Prod
- Horizontal Wells Avg Drift Angle RLF IHS Calculated Avg Drift Angle
Effect of Cleanup Time
Effect of Drift Direction

Brnt Update May 2009

2619 Samples for 3208 Wells

PRODUCTION MAX GASS COMP Highest Rate of Prod

HORIZONTAL_WELLS DRIFT_DIR RLF IHS DRIFT DIR FROM SURVEY
Frac Size vs Production; Color by Prop Concentration

BARNETT 0407 UPDATE
3235 Samples for 3738 Wells

Wise
Denton
Parker
Tarrant

FLUID_VOL IHS

GAS, BO, CUM IHS, CALC

0 10000 20000 30000 40000 50000 60000 70000 80000 90000 100000

0 100000 200000 300000 400000 500000 600000

1.7 1.5 1.3 1.1 0.9 0.7 0.5 0.3 0.1

TOPCONC CALC

0.1
SimoFrac, Trifrac, Zipper Frac
Summary

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