Overview of Hydraulic Fracturing

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Outline

♦ Introduction to Fracturing
♦ Fracture Geometry
♦ Fracture Azimuth
♦ Fracture Conductivity
♦ Selecting a Fracture Proppant
♦ Proppant QA/QC
♦ Summary
Introduction to Hydraulic Fracturing

- Hydraulic Fracturing basically consists of blending a carrying fluid, special chemicals and proppants to make the appropriate fracturing fluid.
- The blended fluid is then pumped down the wellbore into the pay zone at high enough rates and pressures hydraulically fracture the rock.
- As pumping continues at pressures above the fracture gradient of the rock, the fracture creates a wedge and extends the fracture hydraulically.
- Pumped via casing, tubing, or casing/tubing annulus.
Introduction to Hydraulic Fracturing

♦ Pad
  - A “neat” fluid pumped to initially control leak-off and initiate the fracture

♦ Slurry
  - Blended fracture fluid mixed with propping agents ("Proppant")
  - Usually high viscosity to carry increasing proppant loadings.
  - Can also be lower viscosity linear gels or in some cases “water fracs”.

♦ Flush
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Fracture Geometry

♦ Factors affecting fracture geometry.
  ● Well spacing.
    » What is the estimated vs. actual drainage area?
  ● Fracture length.
    » Volume of fluid pumped
    » Volume of fluid remaining in the fracture
    » Geometry of the fracture
  ● Fracture width and height.
    » Viscosity of the fluid
    » Injection rate of the fluid
    » In-situ stresses of the rocks
Fracture Geometry

Fracture Length

- While there are many factors that influence the length of a hydraulic fracture, the fracture length will be dominated by the total volume of fluid pumped vs. volume of fluid remaining in the fracture.
- Given a constant leakoff rate, the length of the fracture will be primarily controlled by injection rate.
Fracture Geometry

✦ Fracture Width
  ● Primarily controlled by the viscosity of the injection fluid.
  ● Controlled somewhat by the Young’s Modulus of the injection zone as a function of viscosity.
  ● Affected to a lesser degree by insitu stress contrast and rate.

✦ Fracture Height
  ● Primarily controlled by the insitu stress contrasts above and below the zone of interest.
  ● To a much lesser degree, height will be affected by rate and viscosity.
Fracture Geometry
Example of Width and Height

![Graph showing fracture stress and width profiles.](image-url)
Fracture Geometry

♦ Most Important Fluid Characteristics
  ● Fluid Loss
    » Minimizing fluid loss will increase the fracture area for a given pumped volume.
  ● Viscosity
    » Affects friction loss, fracture area, and fracture width
    » Affects proppant carrying capacity!
Fracture Geometry

Fracture Extension - Proppant Placement

Shale Barrier

Frac Height 50 feet

Dynamic Frac Width 1/2-1 inch

Perforations

Proppant Suspended in Fluid

1/4 Inch

Proppant-Pack

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Proppant Placed - Pumping Halted Fracture Closure

Pumping in progress Fracture Open
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Fracture Azimuth

The orientation and direction of propagation for a hydraulic fracture will depend entirely on the stress orientations for each individual formation, both vertical and horizontal.
**Fracture Orientation**

- Vertical Stress is Less Than Lateral Stress – **Horizontal Fracture**
- Least Principle Stress is Between Vertical & Horizontal - **Inclined Fracture**
- Lateral Stress is Less Than Vertical Stress – **Vertical Fracture**
A vertical hydraulic fracture will propagate in a direction perpendicular to the Minimum, or Least, Principle Stress orientation.
Fracture Azimuth
Vertical Wells

♦ When $\sigma_v > \sigma_{H1}$ & $\sigma_{H2}$ and $\sigma_{H1} \approx \sigma_{H2}$
  - Then multiple planar fractures can occur.
Fracture Azimuth – Horizontal Wells
Transverse Fracture Plane
Fracture Azimuth – Horizontal Wells
Longitudinal Fracture Plane

Horizontal Wellbore Direction
Why is it important to know fracture azimuth?

- In “tight” (low permeability) formations well locations need to be selected and planned to maximize reservoir recovery with the fewest number of wells and to minimize interference between long fractures.
Fracture Azimuth
Proper Well Location to Azimuth

160 Acre Well Pattern
Azimuth \(\approx N60^\circ E\)
Fracture Azimuth

*Improper* Well Location to Azimuth

160 Acre Well Pattern

Azimuth $\cong N80^\circ E$

Incomplete Reservoir Drainage Between Wells
Fracture Azimuth
Disastrous Well Location to Azimuth

160 Acre Well Pattern
Azimuth ≈ N90°E

Look Out Tanks .... Here it comes!!!!!
**Horizontal Drilling Benefits**

- Larger Area of Contact with Wellbore
- Minimize Fracture Height Growth
- Less Environmental Impact (fewer surface sites)

(a) Vertical Well
(b) Horizontal Longitudinal
(c) Horizontal Transverse
Horizontal Well Fracturing
Wellbore Orientation

Wellbore orientation affects recovery & fracture complexity

- Horizontal well path
  - Transverse Fractures
  - Longitudinal Fractures
  - Fractures oblique to wellbore orientation
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Fracture Conductivity

- Proppant pack permeability \( \text{times} \) settled width
  - \( k_f \times w_f \)

\[ w_k f = (w_f) \times (k_f) \]
Fluid Flow in Petroleum Reservoirs
Restrictions to Flow
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The Ideal Proppant??

♦ Crush resistance (high strength)
♦ Slightly deformable, not brittle
♦ No embedment
♦ Low specific gravity
♦ Chemical resistance
♦ No flowback
♦ Complete system compatibility
♦ Readily available
♦ Cost effective
Which Proppant to Choose??

- Qtz
- Ceramic
- Resin Coated α-Qtz
- α-Qtz
Proppant Categories

Incr. Performance Properties

Incr. Closure Pressure, psi

RC $\alpha$-Qtz

Premium

Intermediate

$\alpha$-Qtz

Ceramics

Intermediate

RC Ceramics

Economy

Bauxite

LWC

Intermediate

Premium
Proppant Selection Criteria

- Finite vs. Infinite Conductivity Fracture
  - Formation Permeability
- Depth/Closure Stress
- Formation Ductility and Embedment
- Median Particle Diameter
- Cyclic Stress
- Multi-Phase Flow
- Non-Darcy Flow
  - Beta Factor
Finite vs. Infinite Conductivity

♦ Mobile fines reduce proppant conductivity.
♦ Sources of mobile fines to reduce propped fracture conductivity
  ● Proppant crushing.
  ● Erosion of fracture face.
  ● Spalling of the fracture face.
Infinite vs. Finite Conductivity

♦ Pore Throat Diameter (PTD) Effects
  - >1/3 PTD     Bridge
  - <1/7 PTD     Flow Thru
  - 1/7 < X < 1/3 PLUG!!
Proppant Crush Effects

Hickory Sand – 8,000 psi Closure

Premium RCS – 8,000 psi Closure
Depth/Closure Stress

Never attempt to choose a proppant based solely on depth and closure stress!!

Northern White vs. Brown
  - Brown – Crushes at 2,000 to 2,500 psi
  - Northern White – Crushes at 4,000 to 5,500 psi
  - Pump proppants in appropriate applications
Embedment

- 20/40 Ceramic, 4,000 psi, 411μ
- 20/40 Jordan, 4,000 psi, 333μ
- 20/40 Ceramic, 6,000 psi, 432μ
- 20/40 Jordan, 6,000 psi, 426μ
- 20/40 Ceramic, 10,000 psi, 542μ
- 20/40 Resin Coated Qrz, 8000 psi
Variations in Particle Sieve Distribution (PSD) can yield a two fold swing in conductivity.

Field Samples – 20/40 Northern White @ 25X

- Median Particle Diameter
  - SPE 84304
  - Variations in Particle Sieve Distribution (PSD) can yield a two fold swing in conductivity.
Median Particle Diameter

Flow Capacity Decreases
Median Particle Diameter

- Published Data (MPD = 0.710 mm)
- Actual Data (MPD = 0.543 mm)
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QA/QC – Proppant Performance

♦ Data defined from outside practices established by governing bodies (e.g. ISO 13503-2 & API RP 19C) can always be excused as non-representative.

♦ Non-ISO data or testing cannot accurately be compared to laboratory modeled proppants.

♦ Design for specification and hold suppliers accountable

RIGHT Material

RIGHT Properties

RIGHT Conductivity

Best Well Production
QA/QC – Proppant Supply Chain

MINING COMPANY

MANUFACTURER

TRANSPORTATION

PUMPING SERVICES

OPERATOR

QUALITY

COST $
QA/QC Achieves Valuation!

Wellsite Proppant Performance
Wellsite Quality (API / ISO)
Storage Point Testing
Assume Quality

$
Which Proppant to Choose??

- Qtz
- Ceramic
- Resin Coated $\alpha$-Qtz
- $\alpha$-Qtz
WARNING!

Again, do not attempt to choose a proppant based solely on depth and closure stress!
CHOOSE WISELY!
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Summary

♦ Proper hydraulic fracture design and proppant selection doesn’t just happen.
♦ Many factors to consider!
  ● Each well is unique and should be designed based on individual well parameters.
  ● Modeling and Expert advice is essential.
♦ At the end of the day…..