Keys to Successful Multi-Fractured Horizontal Wells In Tight and Unconventional Reservoirs

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Key Questions for Horizontal Success

• Where Do I Land the Horizontal Well?
• How Do I Complete The Well?
• Where Do I Complete The Well?
• How Many Completions Do I Need?
• How Do I Fracture Stimulate The Well?
• What Fracturing Fluid Do I Use?
• What Pump Rate Should I Use?
Key Questions for Horizontal Success

- Where Do I Land the Horizontal Well? Core
- How Do I Complete The Well? Permeability/Core
- Where Do I Complete The Well? Core
- How Many Completions Do I Need? Permeability
- How Do I Fracture Stimulate The Well? Core
- What Fracturing Fluid Do I Use? Permeability/Core
- What Pump Rate Should I Use? Core

* Core Represents Mineralogy, Rock and Geomechanics
Keys to Horizontal Success

• Design For Success Through Petrophysics
  – Ductility (Mineralogy, Rock & Geomechanics)
  – Permeability

• Completion(s) & Stimulation(s)
  – Fracture Length & Lateral Length

• Execute, Execute, Execute
Presentation Outline

• Historical Perspective: Horizontal Wells
• Horizontal Well Characterization & Objectives
• Basis of Water Frac Designs – Ductility
• Permeability
• Geomechanics
• Summary
Horizontals: A Historical Perspective

Horizontal Drilling Boom
1998 Only 40 Horizontal Capable Rigs In U.S.  
2008 28% Of U.S. Rigs Horizontal Capable  
2011 57% Of U.S. Wells Are Drilled Horizontal

- First
- Russia
- Cold Lake
- East Texas
- North Sea
- Thermal
- Austin Chalk
- Coning, Empire Abo
- 1st Barnett

Year


SPE Horizontal Well Papers

Unconventional
Well Characterization & Objectives

Metrics Used To Determine The Optimum Distance Between Fractures/Compleions

The IP And Annualized Rate Metrics Are Based On The Distance Between Fractures When Interference Occurs At 30 Days Or 365 Days, Respectively.
Well Characterization & Objectives

Effect Of Lateral Length On Completion Optimization

The Longer The Lateral The More Completions To Be Optimal

- 4,000 Feet
- 3,000 Feet
- 2,000 Feet
- 1,000 Feet

Number of Fractures

Net Present Value, M$
Well Characterization & Objectives

Effect Of Fracture Length On Completion Optimization

The Longer The Fractures The More Completions To Be Optimal
Well Characterization & Objectives

Unconventional → Tight → Conventional

Distance Between Fractures, Feet

Control ← Limited Control ← No Control

Cased & Cemented ← External Packers ← Open Hole

Reservoir Permeability, md
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Basis of Fracture Design

- Ductile
  - XL Gel
  - Foam
  - Linear
  - Hybrid
  - Slick Water
  - Brittle

Increasing Viscosity

Increasing Prop Vol.

Increasing BPM
Schematic of a Water-Frac

Un-propped Crack Tests Integrate The Lab Results With The Field & Explains The Effect Of Poor Proppant Coverage!
Water Frac Guidelines
Must Depend on Un-Propped $k_{fw}$

$F_{CD-Vert} = \frac{(k_{fw})_{Unpropped}}{k \cdot H_{F-Unpropped}}$

As Long As $F_{CD-Vert} > 2$
The Propped Fracture Height Doesn’t Matter!

For $(k_{fw})_{Un-propped} = 1$ mdft
$H_{F-Un-propped} < 50$ feet
Why Un-Propped Crack Testing?

With Un-Propped $k_f w$ a Shale Reservoir Can Support Hundreds Of Feet Of Un-Propped Fracture!

This Is Why Water-Fracs Should Only Be Applied To Tight Unconventional Reservoirs & Proppant Is Always Needed!
Water-Frac’s Must Depend On Un-Propped Fracture Conductivity

Area 4, 5, & 7 Represents Woodlawn & Blocker Fields Where Taylor (CV) Sand Is 100+ Feet Thick!
Mineralogy & Ductility

Proppant And Fluid Selection & Quantity:

Mineralogy

Quartz

Carbonate

Clay

Clay Constituents Less Than 40%
Minimal Swelling Clays (Smectite)
Young’s Modulus & Brittleness

Proppant And Fluid Selection & Quantity:

Young’s Modulus

Young’s Modulus > 3.5 x 10^6 psi
Fits Clastic Modulus Correlation
Un-Propped Crack Test & Ductility

Proppant And Fluid Selection & Quantity:

Un-Propped Crack Conductivity

Best Shale Plays

Marginal Shale Plays

Maintains Un-Propped Conductivity
Fits Within Acceptable Range

Normalized k vs. Normalized Stress
Water Frac Design Example

Barnett Design:
- Young’s Modulus $4 \times 10^6$ psi
  - 25 BPM Need 35 lbs
  - 50 BPM Need 40 lbs
  - 100 BPM Need 45 lbs

Fluid Viscosity, 1 cP
Frac Height, 300’
40/70 Ottawa Sand

Minimal Required Proppant, lbs

Static Young’s Modulus, x $10^6$ psi
Water Frac Design Example

Barnett Design:
- Young’s Modulus $4 \times 10^6$ psi
- 0.25 PPG Need 250 mgals
- 0.50 PPG Need 110 mgals
- 1.00 PPG Need 60 mgals

Minimum Fluid Requirement Does Not Consider Dilation!
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Post Fracture Decline Analysis Example

Logistical & Material Sourcing Issues Required An Extended Shut Down: So We Monitored Pressure Decline!

Stage 6
Stage 5
Stage 4
Stage 3
Stage 2
Stage 1
Post Fracture Decline Analysis Example

Used The Shut Down To Make Real Time Completion & Stimulation Decisions!
Post Fracture Decline Analysis Example

Type Curve Analysis Indicates A Permeability Of 0.018 md!
**Post Fracture Decline Analysis Example**

Average Fracture Dimensions:
- $x_f = 600$ ft, $k_{fw} = 1,000$ mdft

Average Dimensions of Six Stages:
- IP(30 days) = 4.3 mmcfpd

- IP Increased with Fracture Conductivity
- Reserves Increased with Fracture Length

**Graph Details:**
- Cumulative Gas Over Five Years, MMCF
- Gas Productivity, Mscfpd
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Geomechanics of Horizontal Wells

\[ \sigma_v = 10,000 \text{ psi}, \quad \sigma_{H\text{max}} = 7,500 \text{ psi}, \quad \sigma_{H\text{min}} = 6,000 \text{ psi} \]

\[ \beta = 90^\circ \]

\[ \alpha = 0^\circ, \quad BD = 4,000 \text{ psi} \]
\[ \alpha = 30^\circ, \quad BD = 4,154 \text{ psi} \]
\[ \alpha = 60^\circ, \quad BD = 5,574 \text{ psi} \]
\[ \alpha = 90^\circ, \quad BD = 8,500 \text{ psi} \]
Geomechanical Implications

Two Interfering Fractures w/ Contained Fracture Geometry

Slide Keys:
When The Distance Between The Fractures Is > 2 Times The Fracture Height Minimal Effect On Fracture Width & Flow Resistance!
Geomechanical Implications

What Is The Likely Fissure Direction In The Current Stress State Whereby:

- The Natural Fissures Are Open,
- The Fissures Are Conductive, And
- Potentially Contributory To Well Performance

Such A Natural Fissure Is Deemed Critically Stressed
Geomechanical Implications

The Object Of The Completion(s) & Fracture Stimulation(s) Is To Effectively Contact As Much Reservoir As Possible:

– Micro-Seismic Data Used To Assess Contacted Volume Or Stimulated Reservoir Volume

Where:

\[ \text{SRV} = L \times H \times W \] of Micro-Seismic Event Map

Often \[ 2(x_f) \times H_f \times L_L \]
Geomechanical Implications

Stimulated Reservoir Volume

Bigger the Frac Volume the Greater The Stimulated Reservoir Volume & The Greater The Hydrocarbon Recovery

Fisher 2002
Geomechanical Implications

If SRV Important How Do You Get More?

Study showed that higher fluid viscosity slightly increased the tensile failure area.

Study showed that low fluid viscosity dramatically increased the shear failure.
Geomechanical Implications

But Does Complexity Or Stimulated Reservoir Volume Add Up To Hydrocarbon Recovery

Study Showed That SRV Not Very Effective, Neither Was Induced Fracture For That Matter

Additional Simulations Show That SRV May Not Be Critical Or Is It? What About Over The Long Term?
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