Let’s put Engineering back into Fracture Stimulation!

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Pinnacle – a Halliburton Service

Oklahoma Geological Society – Shales Moving Forward
Norman, Oklahoma; 21 July 2011
The Company President asking his staff ..........

......... How are we going to “Frac” this well?

- What are the other Operators doing on their wells?
- How much is it going to cost?
- HOW MUCH!!!!!!
- Why’s it cost so much?
- Do we really need to do all that stuff?
- What stuff can we leave out?
- Do you think it will work if we don’t do all that stuff?
- Who’s going to figure it out if it doesn’t work?
Engineered Completions

Un-Engineered Completions

Schedule:
1) Perforate
2) Pump
3) Repeat

- Horsepower
- Fluid
- Proppant
Eagle Ford Shale - Background

- Depth Range: 4,000’ – 14,000’
- BHT Range: 150°F - 350°F
- $P_{\text{res}}$ Grad. Range: 0.55 – 0.85 psi/ft
- Can produce Dry gas @ 8000’ and High Liquids @ 13,000’, Oil @ 5000’
Eagle Ford Shale - Petrophysics

Mineralogy
Brittleness Index
TOC and Kerogen
Rock Properties
Characterization

Raw Data

Eagle Ford Shale - Petrophysics

SPE 136183
Frac Design in Horizontal: Run Sensitivities

- Injection Rate
- Fluid Volumes
- Fluid Viscosity
- Prop Volume
- Prop Concentration
- Prop Mesh Size
- Others
Near Wellbore Restriction (tortuosity)
Issues with Proppant Placement

• Transverse fracture initiation in perf cluster that is too long can create multiple fractures (SPE 19720).
• Multiple fractures can create tortuosity (SPE 35194).
• Limit perf interval to 4 times the ID of the casing (SPE 86992).
• Use Acid Soluble Cement in Horizontal (SPE 137441)

Image from SPE 19720 by El Rabaa, 1998 and SPE 102616 by Soliman, 2006
Impact of Perforation on the Formation:

Perforation Damage - Crushed, Compacted, “Onion-Skin” Zone

Formation Compaction Zone (Halo)

Perforation Tunnel

Cement

Blue-Dyed Fracture

Un-fractured Halo around compaction zone

Work by Norm Warpinski, 1983
Frac Design Considerations

**Embedment Core Tests**
- **Eagle Ford Shale**
  - 0.35 – 0.77 mm @ 10,000 psi

**40/80 Mesh**
- Lightweight Ceramic

**Haynesville Core Sample**
- SPE 135502
Frac Design Considerations

Dimensionless Conductivity ($F_{cd}$)

$$F_{cd} = \frac{W_f K_f}{X_f k}$$

$$\frac{25 \text{ md-ft}}{500 \text{ ft} \times 0.001 \text{ md}} = 50$$

Non-Emulsifiers needed for Oil

“Hybrid” Frac Fluid

Conductivity

Proppant Conductivity Multi-phase flow

Bauxite 80 md-ft

RCP 25 md-ft

Sand 5 md-ft

Frac Design Considerations

950 cp

35# Polymer Loading

40/sec

Min. acceptable viscosity

Temp.

1000

900

800

700

600

500

400

300

200

100

0

0

10

20

30

Test Time, min

Viscosity at 40/sec

Temperature, °F

Dynamic Conductivity, md*ft

Stress, psi

7000

8000

9000

10000

11000

12000
Frac Design Considerations:
Basic Definitions (SPE 136183)

Water Frac or Slick Water Frac:
• Frac fluid is very low viscosity
• Chemicals or gelling agents are used for friction reduction, not prop transport
• Velocity (not viscosity) used to place proppant
• Injection rates tend to be high
• Typically have alternating stages of proppant followed by fluid “sweeps”

Conventional Frac:
• Frac fluid is high viscosity (from foams to crosslinked fluids)
• Chemicals used to generate viscosity for proppant transport
• Viscosity (not velocity) used to place proppant
• Injection rates can vary greatly (not depending on velocity to place prop).
• Typically have “pad” fluid followed by continuous proppant-laden fluid.

Hybrid Frac:
• Anything in-between a water frac and a conventional frac.
• Typically, a hybrid frac is a combination of the two.
• They tend to begin with a low-viscosity fluid (at a high rate)
• May have alternating proppant volumes with fluid “sweeps”
• Tail-in (sometimes at a lower injection rate) with proppant high-viscosity fluid.
• Large part of job may be crosslinked or just Tail-in fluid may be crosslinked.
Production Comparison: Slick Water vs. Hybrid/Conventional

1st year production
5,500 bbls oil 1st year
16,900 mscf (0.017 bcf)
(Slick Water Frac)

1st year production
150,000 bbls oil 1st year
518,000 mscf (0.5 bcf)
(Hybrid Frac/Conventional)

Choke Sizes: 10-20 first 140 days
Frac Mapping:

Well Planning

Rosetta Resources – Gates Leases

Lateral Placement

Good Zonal Coverage

SRV – Stimulated Reservoir Volume

Good Well Direction

Good Well Spacing

Monitor Well

STIMULATING WELL
Frac Mapping for Frac Model Calibration:

Side View

Frac Match with Microseismic Events

Top View

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Post Frac Hydrocarbon Flow Profiling

- A hydrophobic tracer is added to each frac stage.
- Each of the hydrophobic tracers dissolves within reservoir hydrocarbons.
- Surface flowback samples are analyzed for the different tracers.
- Analysis verification of stage flow and its relative contribution to production.
Post Frac Hydrocarbon Flow

Stage Production Flow

- Initial Production
- Production after Choke Chg
- Production during Frac Monitor Well
- After Frac Production
- Production after restart
Production Analysis - 1/Rate vs. Cum Prod

- The slope is proportional to the system perm and fracture length
- A constant slope indicates “stabilized” fracture conductivity (after clean-up)
- First trend: must have a **non-negative intercept**
  - Intercept is a qualitative measurement of conductivity of the fracture network
  - Zero intercept = infinite conductivity
  - Positive intercept = finite conductivity
- Second trend: influenced by boundaries
  - Either drainage boundaries or interference between fractures

**2500 ft Lateral with**
- 11 frac stages
- 300,000 lbs per stage

**5000 ft Lateral with**
- 14 frac stages
- 300,000 lbs per stage

Dr Jeff Callard,
University of Oklahoma
SPE 139981 & 142382
The Company President asking his staff ........

....... How are we going to “Frac” this well?

- What are the other Operators doing on their wells?
- How much is it going to cost?
- You Are!
- And you can because you have Data!
- Do we really need to do all that stuff?
- What stuff can we leave out?
- Do you think it will work if we don’t do all that stuff?
- Who’s going to figure it out if it doesn’t work?
Thank You

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