Perforating for Hydraulic Diversion Efficiency in Perforation Cluster Breakdown in Horizontal Wells

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Completion Type

• In US ~ 80% Plug & Perf.
  – Maximum flexibility

• In Canada ~ 80% Packer and Sleeve.
  – Maximum speed

• The Type of Completion You Need is the Best Fit for Your Application.

• HOWEVER – the formation decides what fracture type will be possible.
Fracture Types

• Planar:
  – long half length,
  – much easier to prop,
  – much easier to model.

• Complex:
  – only in naturally fractured formations,
  – cannot easily predict,
  – cannot easily prop,
  – can open 10 to 100 x contact area with formation,
Planar vs. Complex Fracturing - What will the formation allow?

Left: Planar fractures with wide separation.
Right: Complex fracturing with narrow separation.

Separation 75 to > 300 ft depending on permeability.
Higher perm ~ more separation

\( \sigma_{h_{\text{max}}} \gg \sigma_{h_{\text{min}}} \)
Usually No Natural Fractures

\( \sigma_v \)

Planar Fracture

\( \sigma_{h_{\text{min}}} \)

\( \sigma_{h_{\text{max}}} \)

Complex Fractures

\( \sigma_{h_{\text{max}}} \approx \sigma_{h_{\text{min}}} \)
Natural fractures present

30 to 50 ft.
Hydraulic Diversion Range

• First perforation friction seen at about 0.5 bpm/perf (21 gallon per minute through a 0.5” hole).

• Actual backpressure resistance seen at about 1.0 to 1.5 bpm/perf.

• Effective diverting seen at 2.0 to 2.5 bpm/perf.

• Very high friction pressure seen at 3.0 bpm/perf. Sand cutting is very likely.
Perforation Cluster Layout in a Horizontal Well

How many clusters?  What spacing?  How long is a cluster?  How many perfs?

Assume 120 to 200 ft fracture stage.  30 to 50 ft cluster spacing.  2' cluster length.  4 clusters.  
Surface Injection Rate - 80 bpm.  Total volume per fracture stage = 10,000 bbl salt water.  
Perforations - 40 perfs, 1/2" diameter.  10 Perfs per cluster  2.0 bpm/perf

Fracture Stage

Cluster 1  Cluster 2  Cluster 3  Cluster 4

10 Perfs 10 Perfs 10 Perfs 10 Perfs

30 to 50 ft 30 to 50 ft 30 to 50 ft

Perfect Split Rate per Cluster = 20 bpm/perf cluster
Perfect Split Volume per Cluster = 2500 bbls

Can the perforation design help even up the amount of frac fluid each cluster gets?
Clusters Within a Single Frac Stage

- Lack of diversion (hydraulic, ball sealers, viscosity, mechanical, etc.) will generate inequity.
Fractures initiate at top and bottom of the Horizontal well.
- Fractures must re-orientate from Near-field to far-field stresses.

Figure - Local forces around a wellbore. Areas of tension are most likely point of fracture initiation, but reorientation of the fracture may occur as the developing fracture extension leaves the near-well and is affected by far-field forces.
Figure - Areas where the fracture initiates as longitudinal and reorients to transverse may be areas of tortuosity.

Tortuosity from linear frac to transverse frac reorientation is a big concern.
Frac Breakdown

- Frac gradient is usually 0.65 psi/ft to 0.85+ psi/ft.

Breakdown pressure usually spikes and drops back at the frac is formed.

Acid, ball sealers, XGL, and other operations may be necessary to develop a single frac per cluster.

This job was slowly ramped up to develop natural fractures and avoid fracturing downward.
Multiple Breakdowns

Breakout? No low microseismic events!

No sand slugs or rate increases
Pressure Trends

Pressure declining due to rapid opening of large frac area

- 1 to 8 psi/minute increase – stable growth in zone
- 10+ psi/minute increase – breakout coming?

Change in net pressure gain rate

Constant increase
How do fractures from vertical & horizontal wells differ?

- Much more formation contact for a single fracture from a vertical well.
- Very different behavior.

For a 50 ft thick zone with vertical planar fracture in 5-1/2” casing:
vertical well has 100’ of contact with the formation
horizontal well has 1.4’ of contact with formation.
Natural Fractures are Another Challenge

Figure - Area of fracture growth transition in near-well to far-field stresses where fracture and flow tortuosity may likely occur. (Modified from Wallace, et al., 2014)
From the Pump Chart to the formation

Figure - Fracture Pump Chart - Frac Initiation - Multiple Breakdowns

Figure - Microseismic sequence of a single stage of a frac in Barnett shale. The first points indicate a planar development, followed by widening of the microseismic cloud with points in a linear trend.
Conclusions

• The formation is the control in fracture type.
• Rate of injection rate arise and frac fluid type make a difference.
• Hydraulic diversion is a key piece of the puzzle:
  – Each formation and completion design is different.
  – Look for best diversion in the 2.0 to 2.5 bpm/perf range.