Effects of spatial variation of cluster entry friction on hydraulic fracture propagation in multistage fracturing (ARMA 19-1617)

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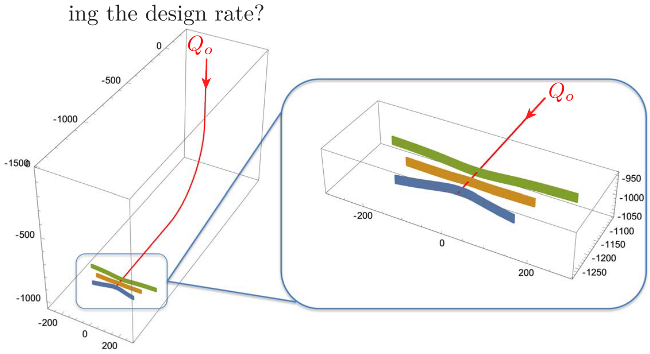
Motivations

- Multi-stage fracturing is the completion of choice of horizontal wells in unconventional reservoirs: the goal is to propagate simultaneously a hydraulic fracture (HF) from each cluster of perforations within a stage (2 to 6 clusters typically).
- **Is simultaneous fracturing stable?**
  - Competition between stress shadow, limited entry & wellbore flow (effect of cluster spacing S)
  - Are all fractures within a stage propagating equally and receiving the design rate?



- Previous studies – limited to planar axisymmetric fractures – indicate that large entry friction promotes uniform growth [1, 2]. However, spatial inhomogeneities of entry friction are typically encountered (e.g. variation of near-wellbore tortuosity) and ruin the effect of limited entry design [1, 3].
- Do these conclusions transfer to the case of long / blade-like hydraulic fractures?

Theoretical model

- Blade-like fracture geometry (constant height H), fractures can curve in the horizontal plane.
- Linear elastic fracture mechanics, homogeneous rock.
- Lubrication flow in the fractures (Newtonian fluid of viscosity μ), negligible leak-off.
- Single phase turbulent/laminar compressible flow in the well (neglecting short transient).
- Entry friction term linking the well-to-fracture entry pressure drop to the entering flow rate as the sum of two terms:
  - a Bernoulli like-pressure drop $\Delta p = f_p Q_{in}^2$ due to perforations,
  - a pressure drop in $\Delta p = f_t Q_{in}^{\beta}$ (with $\beta = 0.5 - 1.5$) due to the near-wellbore (NWB) fracture tortuosity.

An implicit fully coupled scheme

- Displacement discontinuity method – 2.5D elastic kernel [4].
- Finite volume for fluid flow (inside the fractures and in the well).
- 1D implicit level set algorithm based on the complete hydraulic fracture tip asymptotic solution to track fracture tip advance.
- Fracture propagation direction updated after every time-step using the maximum tensile stress direction.
- Fluid partitioning (rate entering the different fractures) solved at each time-step via an additional iterative loop.
- The code has been extensively verified (see paper for details).

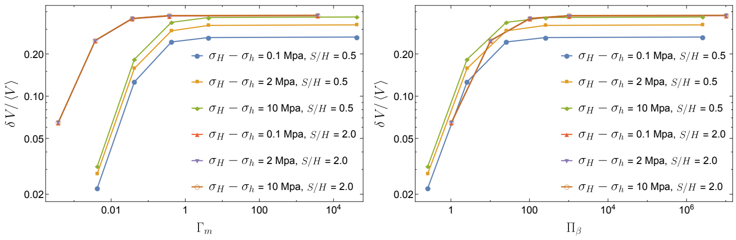
Scaling arguments

For viscosity-dominated blade-like HF, the simultaneous propagation is controlled by the following dimensionless parameters (homogeneous case):

- $\Gamma_m = \left(E'^{3/4}\mu^{1/4} H\right) / \left(f_p (Q_o/N_{fracs})^{7/4} S^{7/4}\right)$ ratio of characteristic stress shadow over perforation entry pressure drop,
- $\Pi_\beta = \left(\rho\, S\, N_{frac}^2\, Re^{-1/4}\right) / \left(D^5 f_p\right)$ ratio of characteristic pressure drop along the stage over perforation entry pressure drop,
- $(\sigma_H - \sigma_h)\sqrt{S}/K_{Ic}$ affecting fracture curving.

Uniform entry friction

For a three fractures stage, a given rock and fracturing fluid, we perform a series of simulations varying Γ_m, Π_β and $(\sigma_H - \sigma_h)$ (as well as S/H).

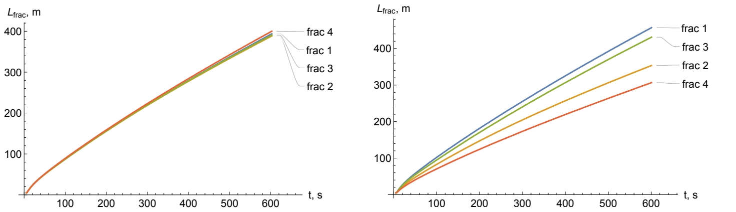


Standard deviation of the fractures volume in the stage as function of Γ_m and Π_β.

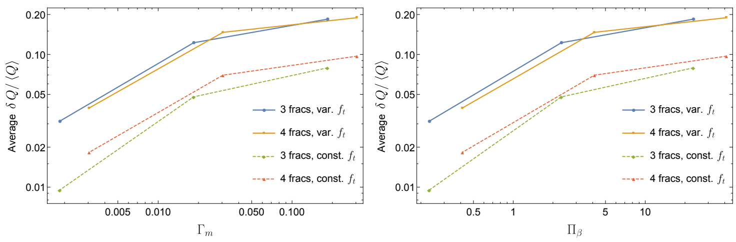
- Large perforation entry friction ($\Gamma_m \ll 1$) promotes uniform growth (mostly encountered in practice).
- Large pressure drop along the stage ($\Pi_\beta \gg 1$) promotes non-uniform growth (cannot be neglected in practice).

Heterogeneous entry friction

We study the effect of near-wellbore stress heterogeneity via a rather small variation of the tortuosity entry friction term f_t: 20% dispersion around the mean value for different realizations (normal PDF).
Other parameters are: $H = 35$m, $S = 25$m; rock properties: $E = 25$GPa, ν=0.2, $K_{Ic} = 1$ MPa m$^{1/2}$; fluid viscosity: $\mu = 0.05$ Pa.s, pump rate: $Q_0 = 0.19$ m^3/s.



Example of fractures length evolution: constant (left) versus heterogeneous (right) near-wellbore tortuosity f_t ($f_p = 8 \cdot 10^7$ Pa (s/m^3)^2 case).



Normalized standard deviation of entry rates (after 10 min.) as function of Γ_m and Π_β for uniform and heterogeneous near-wellbore tortuosity.

Conclusions

- In practical settings, entry friction is sufficient to kill the adverse effect of stress shadow ($\Gamma_m < 1$) and promote uniform growth.
- The pressure drop in the well along the stage promotes non-uniform growth: an effect at least equal to stress shadow if not larger.
- Heterogeneities of entry friction from cluster to cluster (e.g. variation of NWB fracture tortuosity) promote non-uniform growth in all cases. Such heterogeneities are obviously bound to always be present.

References

[1] B. Lecampion and J. Desroches. Robustness to formation geological heterogeneities of the limited entry technique for multi-stage fracturing of horizontal wells. *Rock Mech. Rock Engng*, 48(6):2637–2644, 2015.

[2] B. Lecampion and J. Desroches. Simultaneous initiation and growth of multiple radial hydraulic fractures from a horizontal wellbore. *J. Mech. Phys. Sol.*, 82:235–258, 2015.

[3] B. Lecampion, J. Desroches, X. Weng, J. Burghardt, and E. T. Brown. Can we engineer better multistage horizontal completions? evidence of the importance of near-wellbore fracture geometry from theory, lab and field experiments. In *SPE HFTC*, 2015. SPE 173363.

[4] K. Wu and J. E. Olson. A simplified three-dimensional displacement discontinuity method for multiple fracture simulations. *Int. J. Frac.*, 193(2):191–204, 2015.