ResFrac is a fully integrated hydraulic fracturing and reservoir simulator. The following is an example of a question that engineers and geoscientists can apply ResFrac to investigate. Our web site, www.resfrac.com, has a blog filled with more content like this.

Interested in a free trial of ResFrac?
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Do fractures propagate symmetrically?

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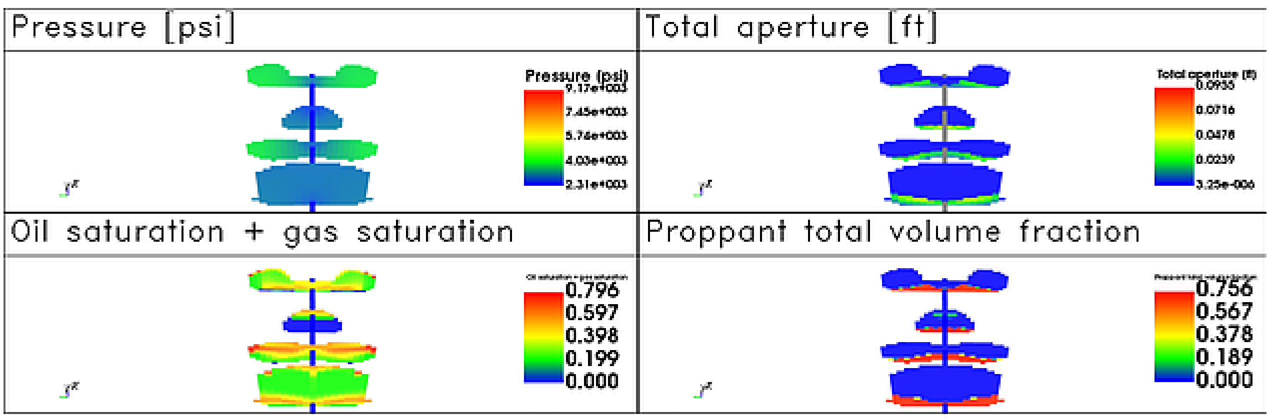
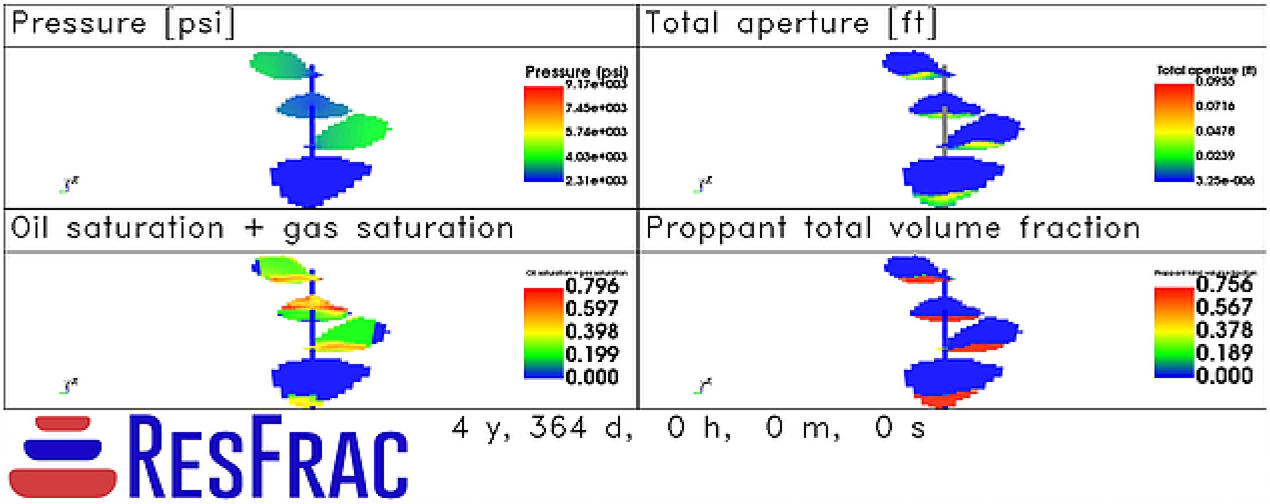
Typically, hydraulic fracture simulations predict symmetrical propagation away from the wellbore. For example, the figure below shows a ResFrac simulation of fracturing and production in a 200 ft horizontal stage with 50 ft cluster spacing. For visibility, the axis is stretched 15x perpendicular to the fractures. The camera looks down on the fractures from above, in the direction of the well azimuth. The fractures are identical on either side of the well.



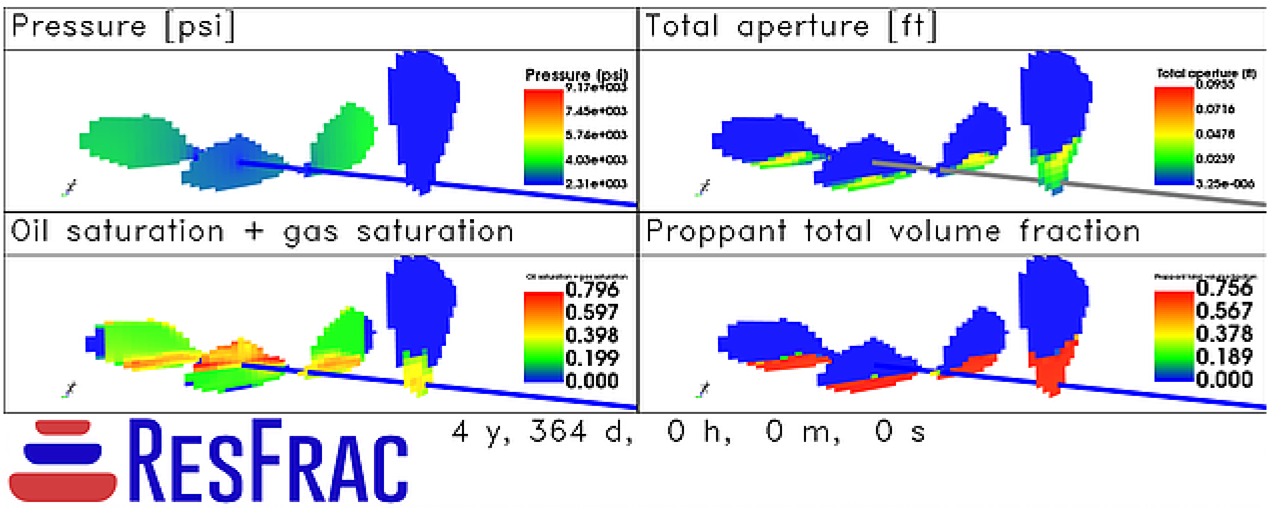
4 y, 364 d, 0 h, 0 m, 0 s

Recently, a colleague, Peter Kaufman, asked me an interesting question: is symmetrical propagation realistic? He pointed out that fracturing simulations are set up with vertical layering, but usually neglect lateral heterogeneity. Because of the laterally uniform properties, the problem setup is symmetrical. On the other hand, reality is not symmetrical because real formations have heterogeneity. Peter asked - if you set up a simulation with lateral heterogeneity, how will this affect the symmetry of the results?

To test, I reran the above simulation with a small amount of random heterogeneity. In each element, the fracture toughness is set to a random number plus or minus 10% around the default value. The result is shown below. Even though the heterogeneity is small, the simulation result is completely asymmetrical.



Here is a side-view:



The asymmetry is caused by stress shadowing. The fractures minimize stress shadowing by growing in different directions. Each of the four fractures propagates in a different direction - up, right, down, and left.

If the simulation setup is completely symmetrical (as in the first simulation shown above), the system is in a ‘metastable’ state. A metastable state is like a ball balanced at the top of a ridge. The ball is motionless, but even a tiny nudge allows it to slide off in one direction or another.

Stress shadowing is minimized if the fractures to propagate asymmetrically. But the system can get stuck in a symmetrical state because of the symmetry of the problem setup. Any small perturbation that breaks symmetry allows the system to evolve to the asymmetric state. In simulations with very strong stress shadowing (very closely spaced fractures), I sometimes observe asymmetric results, even if I use a symmetric setup. Evidently, tiny numerical approximation errors (which occur at the 12th significant digit) can be enough to perturb the system out of the metastable symmetric state.

Real formations have heterogeneity. Therefore, any time we have multiple fractures forming along a well, we should expect asymmetric fracture growth. This idea is surprisingly difficult to test with field data. Microseismic can be used to map the propagation of fractures in the formation. However, resolution is fairly coarse. If you have multiple closely spaced fractures, microseismic will unable to resolve whether both fractures propagate equally in both directions or if the fractures propagate in opposite directions.

If fractures tend to propagate asymmetrically, there are significant implications. Cluster spacing is often optimized using calculations that assume fractures propagate equally in both directions away from the well. If fractures actually propagate in only one direction, the effective cluster spacing is doubled. In the asymmetrical simulation above, the fractures grow up, down, left, and right. Considering these complex geometries, it is questionable whether we can model production with any idealized, consistent fracture geometry. Proppant placement is also strongly impacted by the complex fracture geometry created by the stress shadowing, which profoundly impacts flow during production.

Viscous pressure drop along the fracture tends to inhibit asymmetry. If you use a very viscous fluid, it requires additional pressure gradient to drive flow along the length of the fracture. The further the tip is from the well, the more pressure is required to drive flow to the tip. This makes it easier to propagate crack tips that are closer to the well, which inhibits asymmetry. The simulations above used water. The results might have been different with a cross-linked gel. Thus, asymmetry is controlled by the relative strength of viscous pressure drop and stress shadowing.

Based on these results, I am inclined to make 10% toughness heterogeneity the default setting in ResFrac. Reality is not symmetrical, so we should avoid a symmetrical problem setup.

Aside from asymmetry, stress shadowing causes a tendency for flow to dominate into only a single fracture in each stage. However, the perforation pressure drop, which scales with the square of flow rate at each cluster, combats the tendency for localization and forces flow into all of the clusters. If I reran the simulations above without any perforation pressure drop, I would likely see one fracture dominantly propagating. Possibly, there would be two fractures in the simulation with no lateral heterogeneity (due to symmetry), but not necessarily because the problem is not perfectly symmetrical in the direction along the well because one end of the stage is closer to the wellhead, and there is frictional pressure gradient along the well.

The overall behavior of the system - localization, asymmetry, height growth - is controlled by the combined effect of these different processes - viscous pressure drop, perforation pressure drop, stress shadowing, stress layering, and more.