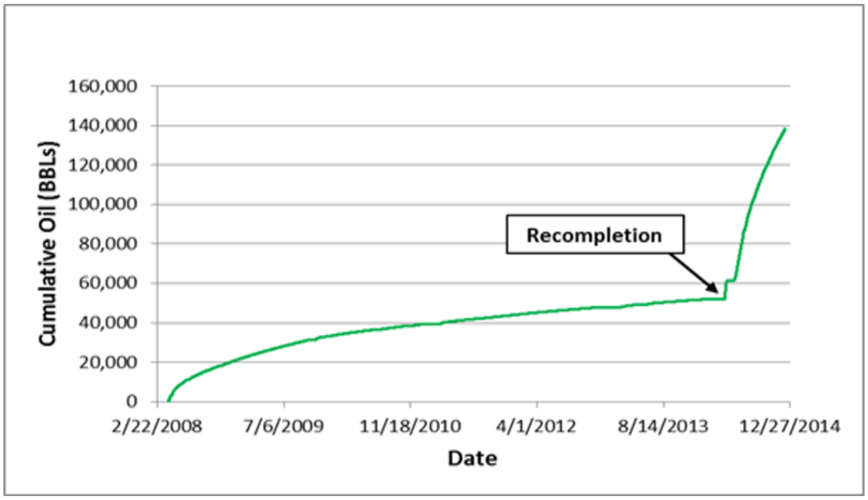
OilFieldGeomechanics

On The Geomechanics of Refracturing



Over the last several years – and particularly with the downturn in oil and gas prices – there has been a growing interest in refracturing operations in Unconventionals. In simplest terms, refracturing is the process of re-stimulating a previously hydraulically fractured well. As in any stimulation program, the value of refracturing comes down to its cost versus the value of the production uplift. A primary reason for the growing interest in refracturing in our current low commodity price environment is that, while the cost of the refracturing operation can be highly variable – from much less than, all the way to equal to, the original completion cost – there are no drilling costs involved, which can save several million dollars over the cost of a new well..

Just as horizontal wells and hydraulic fracturing technologies both significantly pre-date the development of Unconventional Plays, refracturing is not new and has been around for as long as hydraulic fracturing has been (more than 65 years). ARCO, for example, wrote some key refracturing papers about the application and success of refracturing operations on the Kuparuk Field in Alaska in the late 1980s and early 1990s.

Again, refracturing is an economic decision and, just as the industry learned, in the early part of this century, the painful lesson that not all shale plays act like the Barnett, so too, contrary to the common buzz in the media, refracturing is not economic for all Unconventional wells. Critically, refracturing will only be economically successful if: 1) new reservoir can be contacted from the existing wellbore (new hydrocarbons and/or virgin pressure); or 2) the original stimulation was not optimal (e.g., poor fluid cleanup; proppant embedment; poor proppant placement). In simple terms, this means that a refracturing operation has to achieve production – by contacting unstimulated reservoir or improving the original stimulation - that otherwise would not have been produced from the well and the value of this production (using NPV or whatever corporate metric) must exceed the refrac cost. While I have not seen definitive data on the subject, the anecdotal data is that a significant portion of the refracs performed in Unconventionals (and perhaps the majority) are driven by using an improved stimulation which, with better fluids/proppant, means case two for refrac value or, with improved diversion and new entry points, means new reservoir (case one I list above).

Importantly, the geomechanics of these two cases are not necessarily the same! And, to begin to understand the geomechanical components of refracturing, we need to start at the beginning.

If we assume that, for the original well, the stress and pressure are constant along the horizontal lateral, several mechanical effects occur from the original stimulation. First, over some area of natural fractures, the pressure within the natural fractures has increased from the injection of pressurized stimulation fluid. In some portion of this area, the pressure has increased but is below the minimum in-situ principal stress (likely Shmin). In some portion of this area, the pressure has increased above Shmin, and in some portion of this area, the pressure may be above SHmax and/or Sv. Second, within some area a hydraulic fracture may have been created (with pressure above Shmin). Third, proppant has been placed in some portion of the created hydraulic fracture and, perhaps, in some portion of the natural fractures.

As the increase in pressure within the natural fractures and created hydraulic fracture unbalance the forces within the reservoir section, these pressure cause an increase in the stress field around the wellbore (commonly called the Stress Shadow). The change in the stress field is directly correlated to the area of increased pressure. If the area of pressure increase conforms to a simple geometry (e.g., a single, elliptical hydraulic fracture), then the Stress Shadow is also relatively simple. However, if the pressure change is complicated (e.g., a hydraulic fracture with pressurized natural fractures – with some pressure above SHmax or even Sv), then the Stress Shadow can become very complicated.

Once the injection pumps are shut-off, the excess pressure will begin to dissipate (due to the unbalanced forces created). Some of this pressure will move further along the natural fractures (or even extend the created hydraulic fracture), while some may move into the formation (if the permeability is high enough). As this happens, the Stress Shadow will tend to spread out and decline in magnitude (and, potentially, return to pre-stimulation conditions).

Where proppant was placed (in either the created hydraulic fracture or within natural fractures), as pressure dissipates, the fracture will close on the proppant and, since the fracture will remain open due to the proppant, the Stress Shadow from the propped fractures will remain. This suggests that the dynamic Stress Shadow (related to the pressure change) is temporal and larger than the static Stress Shadow (related to the propped fracture area).

So largely, this is the status just prior to production. And with production, pressure declines – both within the fractures and, potentially, within the formation proper. Whatever stress changes occur from this time forward are related solely to production pressure changes.

As the pressure declines, the effective stress acting on the proppant in the hydraulic fracture, on the bridges and cement within the natural fractures, and on the formation where the pore pressure has declined, increases. As a result, the hydraulic fracture closes somewhat (and proppant embedment increases), the natural fractures close, and the formation where pore pressure has declined begins to compact. All of these result in a decrease in the stress field – perhaps akin to an Inverse Stress Shadow.

In the event the original geometry was simple (e.g., a single, elliptical hydraulic fracture), the Inverse Stress Shadow (ISS) is relative simple (typically elliptical). In the event the original geometry was complex (with a complex pattern of proppant and a complex pressure drainage pattern in the natural fractures), the ISS is equally complex. Critically, to understand the stress conditions prior to a refrac (and, recall from hydraulic fracturing 101 that the stress field largely controls hydraulic fracture propagation), we need to know the original Stress Shadow (due to the original stimulation) and the Inverse Stress Shadow due to production-related pressure depletion.

The degree to which an Inverse Stress Shadow forms is not just a function of the pressure change but also a function of the stiffness of the proppant, formation, and cement/bridges within the natural fractures. If these were to be very stiff (relative to the pressure change), the ISS could be very, very small. Conversely, if these were of low stiffness, then the ISS could be greater than the original Stress Shadow!

With depletion, the effective stress acting within the hydraulic fracture will increase. This will both compress the proppant and increase embedment. Both of these will lead to a reduction in stress.

Within the non-propped fractures (natural or hydraulic), depletion, and the associated increase in effective stress, will cause an increase in stress on the asperities within the fractures. These may compress or fail – again resulting in a decrease in the stress field.

In addition, production will lead to depletion within the matrix of the formation itself. This local increase in effective stress within the formation will cause compaction of the formation and, again, a decrease in stress.

There are three keys, then, to understanding the stress field post-production (a fourth if we allow for variable stress pre-stimulation) – and pre-refracturing. First, we need to know the dynamic Stress Shadow (i.e., with pressure still on the stimulation). Second, we need to know the static Stress Shadow (i.e., the Stress Shadow on proppant under static pressure). Finally, we need to know the ISS (i.e., the area that has experienced depletion, as well as the degree of depletion). Coupled with these pressure and stress changes, we need to know the mechanical properties of the formation (i.e., the deformation per unit of pressure change). Needless to say, quantifying these issues is NOT easy!

So, when thinking about refracturing from a geomechanical point-of-view, we need to consider that:

- The stress field, rock strength, fracture aperture, and pressure – amongst other factors, affects where frac fluid will travel.

- In the depleted zone, the stress may be lower favoring re-stimulation of the depleted zone.
- In the pre-stimulated area, a pathway may exist (either propped or unpropped) meaning rock does not have to be broken for fluid to move into the formation. This, too, may favor re-stimulation of the depleted zone.
- The pressure within the fractures (hydraulic or natural) will likely be lower. Again, this will favor re-stimulation of the depleted zone.
- There may be some degree of stress rotation, which will alter the azimuth of newly created hydraulic fractures.

This brings us full circle – we refrac a well either because the original stimulation was poor (in which case we pump into the original perfs under, at least initially, likely lower pressures due to the effects listed above) or we refrac using diversion (in which the diversion needs to plug off the original, likely now easier, flow paths from the original stimulation creating sufficient pressure to allow for breakdown and stimulation of zones that did not take fluid originally and that are likely at near virgin treating pressures or higher).

A final comment – two things jump out as impeding a detailed engineering evaluation and design for refracturing. First, the area of pressure depletion is critical to quantifying the geomechanical effects – and few operators really know this, though there is some work on using microseismicity to define this post-refrac. Second, as diversion from the likely easier, original, stimulation flow paths is critical, understanding diversion physics and interpreting diversion response is critical.