



Hydraulic Fracturing: ***Of Magic and Engineering***

Part 1

Several years ago, I attended an industry conference where a well-known rock mechanics researcher made the comment that hydraulic fracturing in shales was 'magic'. Initially, I was not intrigued by the comment since, after all, who among us has not used a bit of hyperbole while making an argument. Take a moment to think of the times you have used 'always' or 'never' to describe the occurrence of something while trying to make a point. However, this researcher said that hydraulic fracturing in shales was 'magic' twice more in the presentation, including the conclusions. Now I was intrigued.

I made a presentation about Stress Shadows several weeks ago (I will be a 2016-17 SPE Distinguished Lecturer on the topic) and had two interesting comments from the audience. The first comment, and I am paraphrasing, was 'we don't see Stress Shadows so they must not be happening'. Fair enough, but how would you 'see' Stress Shadows anyway? The second comment came about from my effort to show the effects of Stress Shadows (in this case, on the pattern of microseismicity) where the discussion got into hydraulic fracture modeling and the idea that 'we do not know the physics of hydraulic fracturing' enough to make accurate models. Intriguing to say the least.

As many of you know, the first experimental hydraulic fracturing operations, in the Hugoton, were performed in 1947 – nearly 70 years ago. Since that time, we have learned a lot about hydraulic fracturing, but the fundamental physics of hydraulic fracturing (HF) have been known for decades. That is:

- *For well stimulation, an HF consists of: 1) generation of the fracture; and 2) filling the fracture with proppant to keep it open to provide a highly conductive pathway for hydrocarbon flow.*
- *An HF is created only when the injection rate exceeds the flow capacity of the formation. If the flow capacity of the formation (either into the matrix or natural fractures) is greater than the injection rate, no HF may form at all. In addition, once an HF is propagating, if the leakoff rate (loss of fluid from the hydraulic fracture) into the matrix or natural fractures exceeds the injection rate, the HF will stop propagating and begin to close.*
- *Hydraulic energy, in the form of pressurized frac fluid, is controlled only in the well (or to the perforations); past this, the flow path of the omni-directional hydraulic energy is largely controlled by the reservoir and always follows the path of least resistance.*

- *Net pressure – the difference between the fluid pressure inside a hydraulic fracture and the minimum principal stress – is the primary metric for the amount of work being done to the formation while hydraulic fracturing. Commonly, net pressure is +/- 300 psi or less.*
- *The tensile strength of most formations is +/- 10% of the shear strength of the formation (i.e., the tensile strength is +/- 1/10th that of the UCS value). Since the injected hydraulic energy (pressurized frac fluid) will always find and follow the path of least resistance, hydraulic fractures are commonly formed in tension (not shear) and open against the least principal in-situ stress (in a normal faulting environment, this means that the created hydraulic fracture propagates vertically towards the maximum horizontal stress, SHmax, and opens against the minimum horizontal stress, Shmin). However, there are situations where the path of least resistance to fracture propagation is not dominated by the stress state but rather by the mechanical properties of the formation (i.e., ductile formations which are difficult to fail in tension or naturally fractured formations where the natural fractures dominate the hydraulic fracture propagation path).*

So where does the ‘magic’ come in? What are the uncertainties in the physics involved (not uncertainty in the data to evaluate the physics, but the physics itself)? Why do we have to ‘see’ the physics (like Stress Shadows) to believe that they exist?

By way of explanation, we could first simply fall back to the human pre-historic tendency to attribute magical powers to things unknown (at the time). Clouds, rain, hail, and fire were all, for example, feared and worshiped by numerous primitive human tribes, yet today the understanding of each of these is taught to children in elementary school. Further, the need to ‘see’ (or touch or taste or hear or smell) something in order to accept it and understand it is also a basic human tendency. Surely, however, when it comes to hydraulic fracturing we are beyond this.

So, finally, we might simply chalk it up to semantics – what one person sees as uncertainty in ‘data’ is another person’s uncertainty in ‘physics’.

Whether it is because of (the fear of) the unknown or because of incorrect terminology, these beliefs have significant negative impacts on both new and experienced personnel within the industry (and, perhaps more critically, society at large). The belief that hydraulic fracturing is ‘magic’ or we don’t understand its physics leads to (incorrectly) a:

- *Lack of trust in numerical predictive models – which leads to the belief that we are unable to predict and assess hydraulic fracturing behavior before pumping the job;*
- *Resorting to trial-and-error job designs – which is both costly and promotes future incorrect actions because the correlation established during the trial-and-error process lacks causation;*
- *Lack of advancement in the associated physics – why, for example, try a new fluid or process if we can’t resort to anything but expensive trial-and-error to show its value; and*
- *Lack of focus on critical steps towards improvement – why collect more (or more detailed) data if there is no predictive value in it (other than, again, feeding a trial-and-error approach that lacks causation).*

It should go without saying that there are many, many folks who do understand hydraulic fracturing and the fundamental physics behind it. And there are many, many folks who can and are engineering their hydraulic fracture stimulations using sound physics and sound numerical tools. However, there are many who are not...and these folks can and do influence not only the next generation of engineers and scientists but also society at large – which poses a great challenge to the industry.

Part 2

In my previous post regarding the ‘magic’ of hydraulic fracturing, I related several negative effects that are occurring within the oil & gas industry because of the belief that hydraulic fracturing in Unconventionals is (at least partially) beyond our capacity to understand and predict (ergo, the reference story about hydraulic fracturing in shales referred to as ‘magic’). These negative consequences include a lack of trust in numerical predictive models, resorting to trial-and-error stimulation designs, a lack of advancement in the associated physics, and a lack of focus on critical steps towards improvement such as collecting more (or more detailed) data.

A critical point that I did not dwell on in the previous post was the issue of ‘physics’ versus ‘data’. Perhaps, again, the issue is one of semantics – one person’s ‘physics’ is another person’s ‘data’. But let’s dispel that possibility up front.

Recall Newton’s Second Law of Motion that states that Force, F , equals Mass, m , multiplied by Acceleration, a ($F=ma$). The ‘physics’ of Newton’s Second Law is that the sum of the forces acting on a body (F) must be equal to the mass of the body (m) times the acceleration of the body (a). We know and accept that these physics are correct. For example, due to the lower gravity on the moon, astronauts weighed less and were thus able to (and were predicted to be able to) move and jump around even in their bulky spacesuits. Recall, for example, that astronaut Alan Shepard even ‘played’ golf on the moon in 1971!

Perhaps a more concrete example is the common behavior of street and drag racers where, in order to achieve greater acceleration of her car, a driver will strip out all the unnecessary components to reduce the mass of the car. So the ‘physics’ of Newton’s Second Law is the defined relationship between force, mass, and acceleration. In order to predict the force necessary to create an acceleration (per our drag racer example), it is not enough to know the relationship between force, mass, and acceleration. Rather, we need ‘data’ (i.e., values for the parameters) - along with the physics - to make a prediction.

For hydraulic fracturing then, what are the ‘physics’ and what is the necessary ‘data’? Recall some of the fundamental physics from my previous post:

- *Hydraulic fracturing is about creating volume in the formation, that otherwise did not exist, to stuff fluid (and proppant) into. A hydraulic fracture is created only when the injection rate exceeds the flow capacity of the formation. A good analogy is a balloon with a hole in it. If the hole is large enough, no amount of blowing will inflate the balloon. However, if the hole is relatively small and we blow hard enough (a high enough injection rate), the balloon can be inflated. Similarly, if the flow capacity of a formation (either into the matrix or natural fractures) is greater than the injection rate, no hydraulic fracture may form at all. In addition, once a*

hydraulic fracture is propagating, if the leakoff rate (loss of fluid from the hydraulic fracture) into the matrix or natural fractures exceeds the injection rate, the hydraulic fracture will stop propagating and begin to close.

- Hydraulic energy, in the form of pressurized frac fluid, is controlled only in the well (or to the perforations); past this, the flow path of the omni-directional hydraulic energy is largely controlled by the reservoir and always follows the path of least resistance. Furthermore, there is no injection pressure dial on a pump truck – only an injection rate control. Consequently, the magnitude of the hydraulic energy (i.e., the magnitude of the pressure) is a result of a given injection rate into a formation with a given capacity to take this rate. In simple terms, ignoring friction outside the hydraulic fracture, the injection pressure is controlled by the injection rate relative to the flow capacity of the formation (and, where the formation flow capacity is greater – or easier to create – the injection pressure will be less and, conversely, where the formation flow capacity is less – or more difficult to create – the injection pressure will be higher).*
- The tensile strength of most formations is +/- 10% of the shear strength of the formation (i.e., the tensile strength is +/- 1/10th that of the Unconfined Compressive Strength, UCS, value). Since the injected hydraulic energy (pressurized frac fluid) will always find and follow the path of least resistance, hydraulic fractures are commonly formed in tension (not shear) and open against the least principal in-situ stress (in a normal faulting environment, this means that the created hydraulic fracture propagates vertically towards the maximum horizontal stress, SHmax, and opens against the minimum horizontal stress, Shmin).*
- However, there are situations where the path of least resistance to fracture propagation is not symmetric around the wellbore and not dominated by the stress state but rather by the mechanical properties of the formation (i.e., ductile formations which are difficult to fail in tension or naturally fractured formations where the natural fractures dominate the hydraulic fracture propagation path). Many commercial hydraulic fracture simulators model a single fracture wing and assume that the other wing is symmetric to the first, which is premised on the path of least resistance for hydraulic fracture propagation (both stress and formation properties) being laterally homogenous away from the wellbore. Many field microseismic data sets have shown this assumption to be incorrect!*

So – the critical physics of hydraulic fracturing are: 1) formation flow capacity and its change as a hydraulic fracture propagates (i.e., leakoff); 2) in-situ stress (magnitudes and directions) and pressure; and 3) formation structure and mechanical properties (both stiffness and strength), where the stress and formation properties determine the energy required to create the hydraulic fracture and the path(s) of least resistance it will take.

As another analogy, consider the process of splitting wood for a fire. Hydraulic pressure is not used (at least directly) to split the wood, so the flow capacity issue is moot in this example. What controls the splitting of the wood then? Since no stress is involved, that is moot as well. Which means that what controls the splitting of the wood (i.e., ‘fracturing’ the wood) is the structure of the wood (like knots in the wood) and the mechanical properties of the wood itself. If we had a homogenous piece of wood

(without knots) and knew the strength of the wood fibers, we could make a pretty accurate prediction of the splitting process (both the energy required as well as the direction of the split). So the 'physics' are relatively simple and all we really need is the 'data'.

Largely, this is true about hydraulic fracturing. We know the physics of formation flow (things like Darcy's law), we know the physics of stress and stress orientation, and we know the physics of formation structure (i.e., faults, bedding planes, and natural fractures) and mechanical properties. What we often lack ... is the 'data' for all these things in a 3D volume (and not the 'physics')!

If we assume for a moment that a numerical simulator exists containing the physics described above (and leaving aside frac fluid/proppant physics), what data is needed:

- *The flow capacity of the matrix of the formation, which includes permeability, porosity, and pressure;*
- *The stress field (magnitudes and direction) within the 3D volume that is going to be fractured;*
- *Geological structure in 3D, including bedding, faults and fractures;*
- *Matrix mechanical properties (stiffness and strength);*
- *Structural component (i.e., bedding planes, faults, and natural fractures) mechanical properties (stiffness and strength) and flow components (i.e., aperture and permeability).*

Is getting all this data easy? Heck no – but let's not hide behind 'we don't know the physics' when what we really mean is 'I can't (or won't) collect all that data'!