Fracturing Concepts

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Physics of Fracturing: All solid materials will fail if enough stress is applied. Hydraulic fracturing (as well as pneumatic fracturing) methods use fluid pressure to create the stress needed for a crack to nucleate in soil or bedrock. Once the crack starts, lesser stress is required to propagate it through the medium. Realistically, this implies that fluid fracturing methods will create only one crack because the propagation dissipates the stress. In contrast, explosives create shock waves of stress that can, effectively, outpace the propagation so multiple cracks nucleate.

Fluid fracturing nucleates a single crack, and it can be propagated by continuing to add (i.e. inject) fluid into it. The fracture can continue to grow until it hits an obstruction or the injected fluid leaks out of it into the surrounding permeable media as fast as the injection rate. Of course, the law of diminishing economic returns can affect a feasible limit to size.

Shape and Orientation: The form of the fracture are characteristics of interest and, practically, should be exploited to best effect the purpose of fracturing. All induced fractures have the same sheet-like shape, with apertures typically less than 1% of the extent. Variation of injection rate and fluid viscosity as well as local geological / geotechnical properties can impose some effect on this ratio as well as upon the ratio of the two major dimensions of length and width.

In situ state of stress controls the ultimate orientation of an induce fracture. Vertical in situ stress is typically the weight of the overburden. Lateral in situ stress can result from a variety of geologic processes. The fracture will propagate in the plane that is perpendicular to the least principal in situ stress, i.e. it will overcome the least resistance. Essentially the fracture plane will demonstrate whether it is easier to “jack-up” the overburden or “push” the oceans apart.

Manipulating Stress: That said, it is important to note that the fracture nucleates in the plane defined by induced stress overcoming the strength of the solid media. Since fluid fracturing relies upon pressure, the induce stress can be manipulated by constructing the geometry of the surfaces upon which the pressure is applied. So, we diligently create thin gaps of known orientation so that the greatest stress can be developed at the perimeter of the shape. For example, pressure applied in a disk-shaped cavity focuses stress in the hoop defined by the cylindrical surface, and a fracture nucleated in the plane of this disk will propagate some distance before being diverted to its ultimate direction by the least in situ stress.

Conversely, application of fluid pressure to a long cylinder results in a fracture that has a major dimension parallel to the axis of the cylinder. This is why we avoid trying to create horizontal fractures from open well. (It also the reason that a frozen pipe fails with a split parallel to its axis.)

Propagation: Sometimes it is said that fractures “follow the path of least resistance.” That is true as long as resistances being considered are the matters of in situ stress as discussed above. Notably, many readily observable characteristics of a formation do not necessary align with the in situ stresses. These include coloration, lamella, variations in stratigraphy, existing fractures, etc. Consequently, a propagating fracture may cut across features that might be perceived as able to control the fracture form. A most prominent example was observed during the Stressoil project when a excavation revealed that a fracture created with white sand cut across a fracture created two days earlier with red sand.

Hydraulic fractures grow in episodic bursts even when the injection rate remains constant. In other words, the fracture expands as a collection of lobes, each lobe created during a portion of the overall injection event. In the end, the fracture comprises many lobes. Each lobe is filled with whatever material is being injected while it is being created. Since lobes created early are closest to the injection point, the last material injected ends up the farthest from the injection well. This order contrasts with the might be expected if the fracture grew uniformly with later material displacing earlier.

Related Phenomena: Fracture features can be created in a wide variety of media. Of course brittle rocks fracture. Also, physics allows fractures to form in material that might seem to be more compliant. For example, clay materials that traditionally are conceived as plastic will exhibit Type I (tensile) fractures when subjected to internal fluid pressure. Interestingly, failure processes vary similar to fracturing occur in non-cohesive materials such as sand packs. Recent work at Georgia Tech shows that thin spaces of narrow aperture, which are identical in form to fractures, can be propagated through sand packs because the friction of rearranging the grains at the tip of the space mimics the energy consumption of matrix failure that occurs during creation of proper fractures. Accordingly, fracturing methods and models can be applied to such formations.