Geo Energy

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Hydraulic Fracturing

Well stimulation may be required for reservoirs that are not performing optimally. The justification for stimulation is always an economic justification, where the increased productivity or injectivity is weighted against the cost of the treatment. Key input is the knowledge about the reservoir: what is the permeability; is there a natural fracture network; is there any soluble damage. Low permeability reservoirs may be stimulated best using hydraulic fractures, while reservoirs with soluble damage around the wellbore are candidates for acidizing.

Fracture Modelling

Hydraulic fracturing is an unstable process in the reservoir in which the rock is broken to make highly permeable travel paths between the reservoir and the well. Rock mechanics is essential input in designing hydraulic fractures. Fracture stimulation is usually tensile fracturing (mode I, see Figure 1). To model the process, input is required about the elasticity of the formation, the stress, and the failure criterion (Figure 2). Furthermore, the injection or production of large amounts of water has implications for the stress field through the poro-elastic and thermo-elastic effects. A final important issue is the strength of the cap rock, which is required to contain the fracture in the target formation (Figure 3).

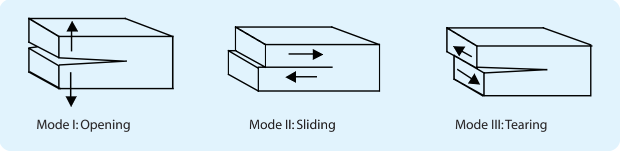

Figure 1. Fracture modes

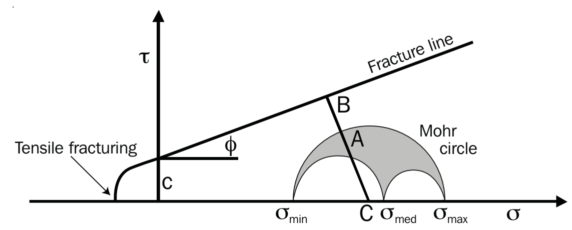

Figure 2. Graphical representation of the effective stress in the Mohr circle and of the Mohr-Coulomb failure line, in 3D.

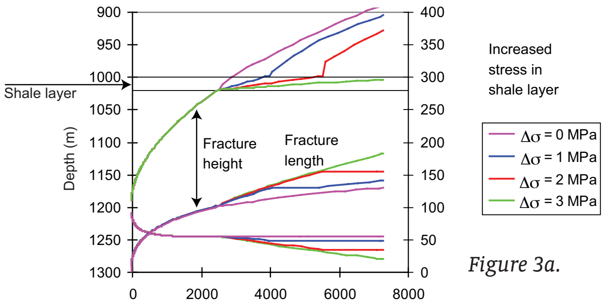

Figure 3a.

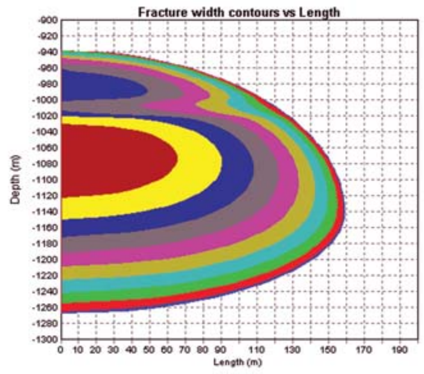

Figure 3b.

Figure 3a and 3b. Effect of strength of overlying shale on fracture containment: in this scenario, a stress contrast of 3 MPa is required. The fracture width contours at different depths in the reservoir are given for the final fracture dimensions resulting with a contrast of 2 MPa.

The propagation of fractures can be modeled by coupling the appropriate conservation laws. These are conservation of mass and conservation of energy. Conservation of momentum is not relevant as fracturing is usually a slow process. The conservation laws must be coupled with constitutive equations like the Darcy equation, Hooke's law for elasticity, and a fracture propagation criterion. A visualization of the complete process is provided in Figure 4.

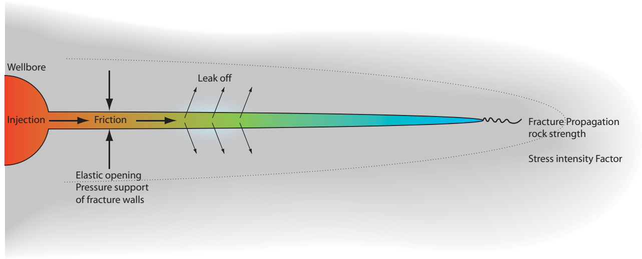

Figure 4. Coupling of the different processes in fracture propagation.

Data collection

The collection of relevant data is a crucial step in the success of a hydraulic fracture treatment. This is the case for data to be collected before the treatment as well as data during the treatment. Data before the treatment are static data (geological input, stress measurements, natural fractures, core data, etc) and dynamic data (well tests, microfrac tests, minifracs). During the treatment, more dynamic data need to be collected (pressure data, tiltmeter mapping, passive seismic) to optimize the operations real-time and to build a database for hydraulic fracturing in that region. Figures 5 – 7 give examples of these.

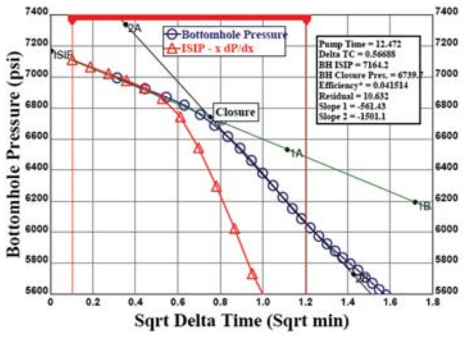

Figure 5. Minifrac test to determine fracture closure pressure.

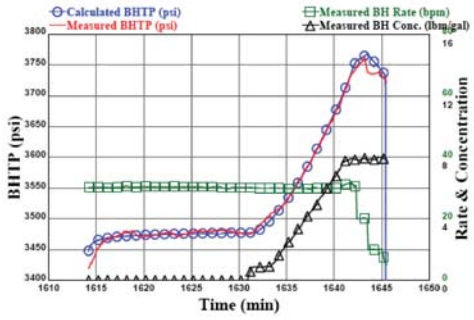

Figure 6. Measured and calculated pressure and rate traces during a hydraulic fracture treatment.

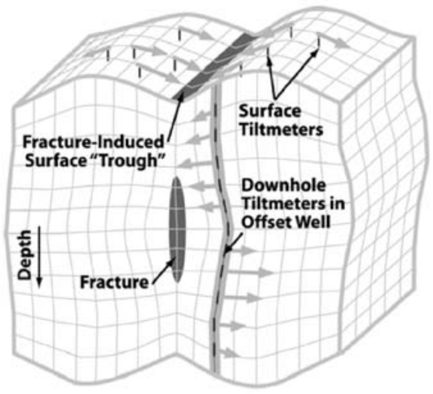

Figure 7. Tiltmeter mapping of a hydraulic fracture, both at the surface and in an offset well.

Naturally Fractured Reservoirs

A number of specific issues pop up when fracturing is considered in naturally fractured reservoirs. This is of great relevance to geothermal applications in, e.g., hot dry rock. There is a recent equivalent in the hydrocarbon industry in the very low-permeability Barnett Shale fields in Texas (Figure 8). These fields are now produced economically thanks to massive hydraulic fractures with water and small amounts of proppant. The economics are different because of the very low permeability: the goal of a hydraulic fracture treatment is now to connect with a substantial volume of the natural fracture network. This is supported by passive seismic monitoring, by which the stimulated area was mapped (Figure 9). A recent analysis showed a clear correlation between stimulated volume and productivity (Figure 10).
The field experience in this area and elsewhere shows that building a knowledge database is crucial in optimizing the treatment performances.

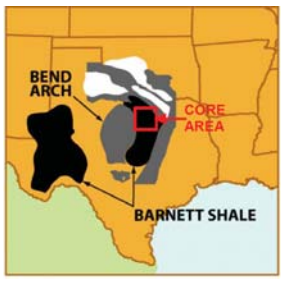

Figure 8. Geographic position of the Barnett Shale fields in Texas.

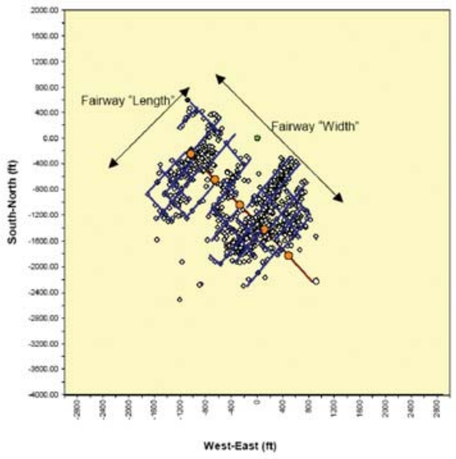

Figure 9. Map of seismic events during hydraulic fracturing in the low-perm Barnett Shale.

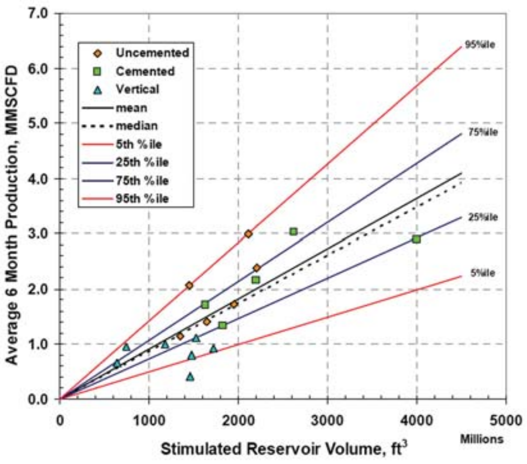

Figure 10. Correlation between stimulated volume as measured with passive seismics and the production.

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