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Can Microseismicity be Used to Define Effective Permeability?

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Summary

In general, seismicity, although occurring at discrete locations and times during a stimulation, can also be thought to behave collectively in response to changes in local stress conditions. By identifying similarities in seismic character of individual events, such as seismic efficiency, seismic energy release, stress release, the rock behavior can be statistically assessed and described in terms of deformability, stress state and the ability of the rock to transfer stress load. Differences in rock behavior spatially and spatio-temporally can further be used to define the effectiveness of a stimulation program. Urbancic et al., 2017 showed that utilizing this approach, referred to as Dynamic Parameter Analysis (DPA), in conjunction with Rate Transient Analysis (RTA), one can define the geometric distribution of rock volumes that have the highest potential for contributing to near term production. By integrating DPA with RTA it was also shown that a definitive Stimulated Reservoir Volume (SRV) could be established and thereby increase confidence in the volumetric extent of production.

In addition to establishing the SRV, RTA allows for the estimation of productivity parameters such as $A\sqrt{k}$, where A represents the surface area accessible for production and k is the effective permeability (Figure 1). Both k and A cannot be uniquely determined from production analysis alone. Typically, permeability is measured in the lab (e.g. pulse decay, pressure decay, etc.) or in the field (e.g. diagnostic fracture injection test, DFIT), and used to provide an estimate of area, however, an under or over-estimate of A or effective permeability k can result in non-uniqueness of the design models (Figure 2).

Typically, the RTA of early-time production data from tight, fractured wells invariably reveals linear flow behavior, identified by a straight line on a square-root of time plot (Figure 3). The presence of linear flow allows for the determination of a bulk productivity term referred to as the 'linear flow parameter', which is the product of the exposed area to flow and the square-root of the reservoir permeability, $A\sqrt{k}$.

Microseismic analysis potentially provides an alternative approach that could further constrain model development. By considering the stimulated area as a penny shape crack with stress release over the entire rupture surface, values of source radius and thereby fracture length and surface area can be determined for individual events that form the collective behavior related to SRV as constrained by production data and thereby provide the surface area of all connected fractures to the wellbore. This in turn would allow for determining effective permeability uniquely.

In addition to DPA and source analysis, with sufficient geometric array coverage, the potential exists for an explicit determination of fracture plane orientations by using Seismic Moment Tensor Inversion (SMTI) analysis coupled with Stress Inversion Analysis (SIA) thereby allowing for the degree of fracture connectivity to be established and related to the ability of the stimulated fracture network to support flow back to the treatment well (Percolation). It also can be used to establish the portion of the fracture network that is partially connected back to the treatment well, which could result in future production.

By utilizing these techniques, we attempt to uniquely link connected fracture area from microseismic data analysis to RTA-estimated fracture area from linear flow analysis, thereby establishing the validity of the approach through examples and show the benefits for constraining model development. In the process we discuss the reliability of obtaining estimates of effective permeability and how it can be used to further constrain practical model development. Additionally, we propose to examine the effect of overlap in DPA volumes and the role that plays in terms of permeability effectiveness. Our primary objective of combining these analyses is to extract additional value from the integration of these approaches by better characterizing the fracture area.

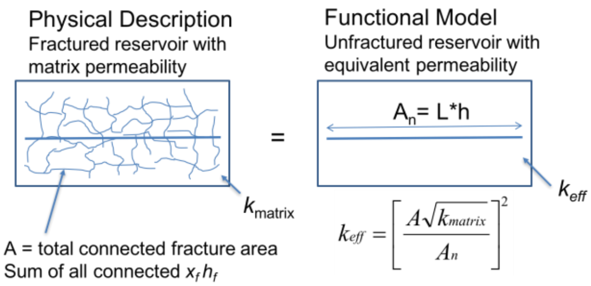

Figure 1. Schematic of fractured reservoir, where total area (A) is defined by the total connected fractures within the frac half length and width. And can be represented by a simple unfractured reservoir model with equivalent permeability to observed in the fractured reservoir. For unconventional shale play, the matrix permeability is negligible.

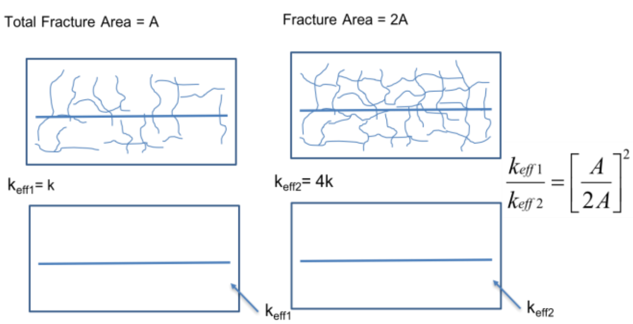

Figure 2. Simple model relating fracture area to effective permeability. As shown, doubling the total fracture area is equivalent to a 4x increase in effective permeability. However, the doubling of the effective permeability is equivalent to a 1.4x increase in total fracture area.

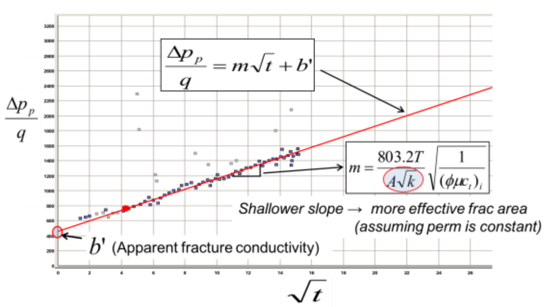

Figure 3. Linear flow behavior analysis.