The influence of pore size distribution on transport properties of rocks

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MOTIVATION

Fractures provide good passageway for fluids to move across between the rock surfaces and thus its dimension affects the permeability and hydraulic conductivity [Brown, 1987; Zimmerman et al., 1990]. The transport properties in rock fractures depend on the aperture size and its distribution. Changes in fracture dimension due to external stresses do not reflect the changes in contact area between the rock surfaces, but also lead to differences in its capability to include fluids. Kang et al. [2016] showed the emergence of preferential flow paths, and thus changes in transport characteristics in fractures under stresses. The ability to infer fracture aperture distribution from flow data would provide significant amount of information for reservoir characterization and monitoring.

We attempted to investigate:

- how the fluid transport properties in fracture medium were affected by compression of rock surfaces with different aperture distributions; and
- whether the transport characteristic properties under different fracture compression could be used to infer the roughness of rock surfaces, and thus the heterogeneity of fracture apertures.

METHODOLOGY

Apertures of fractures formed from two correlated rock surfaces could be considered mathematically equivalent as from a flat upper and a rough lower surface (Figure 1), where the lower rock surface was assumed to follow a log-normal distribution, with certain autocorrelation lengths (λ) and variance (σ^2). The surfaces were at first contact under the reference compression state. Stressing of fractures would result in a compression displacement d. Aperture heights (h) were taken as the non-negative displacement between the rock surfaces. Fractures were assumed to exist in a cubic of rock with side lengths of L and the apertures were saturated with brine.

One hundred realizations of the aperture distributions, of various λ and σ^2 were generated [Ruan and McLaughlin, 1998], and subjected to various compression displacements. Hydraulic conductivity (K) of the fractures were found using the relations: q_{up} = -L J dρ and K = rh/τ after flow simulations. Transport properties were inferred from the 90% Confidence Breakthrough Interval, obtained from random walk simulations [Kang et al., 2011]. Longer Breakthrough Interval implied a more anomalous transport.

RESULTS & DISCUSSIONS

At one compression state alone, some combinations of λ and σ^2 gave fractures of similar hydraulic conductivity (Figure 3), making the inference of aperture distribution from hydraulic conductivity non-unique. At the same time, majority of the cases showing very similar 90% Confidence Breakthrough Interval at reference compression state (Figure 4). Thus it is also insufficient for the inverse analysis.

However, the hydraulic conductivities and 90% Confidence Breakthrough Interval could have distinct changes under compression, even when the fractures had similar properties at one compression state (Figure 5). In general, as compression increased, the apertures narrowed down, thus the hydraulic conductivity and the flow flux in the fracture decreased due to shrinking of flow paths. The averaged breakthrough time as a result increased. Moreover, compression of fractures could completely close down some apertures and caused the emergence of preferential flow paths, therefore transport became more anomalous as fractures were compressed (Figure 6).

CONCLUSIONS

It was shown that:

1. Fracture aperture roughnesses could be statistically represented using the parameters of autocorrelation length and surface height variance;
2. Conventional steady state hydraulic conductivity measurement cannot uniquely resolve the roughness distribution of the fractures;
3. Measurement of breakthrough time help to constrain some aspect of the roughness distribution; and
4. Breakthrough times under different compressions help to resolve the roughness distribution of the fracture surface.

REFERENCES


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Figure 1: A schematic illustration of the reference fracture cross-section where aperture of height h was formed from a flat upper surface (S_1) and a rough lower surface (S_2). It was to be subjected to a compression displacement d.

Figure 2: An example of simulated (a) flow flux, and (b) cumulative breakthrough curve with its breakthrough interval.

Figure 3: Hydraulic conductivity of different aperture distributions under reference compression state.

Figure 4: 90% Confidence Breakthrough Interval of different aperture distributions under reference compression state.

Figure 5: For some fractures with similar hydraulic conductivity at reference compression state, the percentage change under compression.

Figure 6: For two fractures which had similar initial hydraulic conductivity, their (a) aperture fields, (b) flow flux fields, and (c) breakthrough curves at reference and (d) high-compression states respectively.