Statistics Of Numerical Experiments With Multi-Fracture Systems

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Abstract

Modeling of fractured porous media systems is currently of high interest in various academic and applied fields, mainly in the geological and material sciences. The very different scales of the region of an application case on the larger end and the fracture on the lower end pose a challenge for modeling. If the fracture flow is modeled in detail on the small scale, limits of computational resources, storage or execution time, may be reached. Thus a mixed dimensional approach is often given preference. Representing the fractures in a lower dimension than the entire region (i.e. 1D in 2D, or 2D in 3D) enables the modeling of multi-fracture systems with a multitude of fracture objects, while not neglecting the background material.

Within the Subsurface Module of COMSOL Multiphysics® the option for mixed-dimensional modeling is available. Using the Darcy's Law physics interface and the Fracture Flow feature, we examine the characteristics of multi-fracture systems in 2D, where fractures are treated as 1D line segments. Figure 1 illustrates the flow field. The color map depicts hydraulic head, decreasing from the inflow boundary on the left to the outlet on the right. The fractures are depicted as black lines. Grey lines represent streamlines. It can be clearly observed that the density of streamlines increases near to fractures with dominating horizontal orientation. It also shows that there is a reduced hydraulic head gradient along these fractures.

Each scenario is created using COMSOL® user-defined methods. During execution of the method fracture lengths and orientations are chosen randomly. As post-processing the effective hydraulic conductivity as major hydraulic property of the entire system is determined by computing the total flux determined using line integration at inflow and outflow boundaries. Results of the distribution of hydraulic conductivities are presented in histograms, fitted to statistical distributions (Figure 2).
Further scenario runs served for a parameter sensitivity study. We examine the influence of the multi-fracture characteristics: number of fractures, minimum and maximum fracture length, fracture thickness, fracture and matrix conductivity as well as conductivity ratio between fracture and matrix permeabilities. For the latter parametric sweeps were utilized. Statistics for the results for different parameter settings are presented in boxplots (Figure 3).
Finally functional relationships between the parameters of the multi-fracture setting and the resulting mean conductivities are determined. Positive correlations were found between the effective hydraulic conductivity with the number of fractures, with the maximum fracture length, and with the conductivity ratio. The correlation is slightly negative with the minimum fracture length. The dependency on maximum fracture length is even better represented by quadratic and cubic functions.
The results of the simulations and the statistics provide clues how the hydraulic conductivity of a sample is affected by properties of the fracture system. The presented approach may enable the prediction of conductivity from basic fracture characteristics.

Figures used in the abstract

Figure 1 : Figure 1: Illustration of the flow field in one out of several 100 computed scenarios.

Figure 2 : Figure 2: Hydraulic conductivity distribution for a set of 40 scenarios

Figure 3 : Figure 3: Boxplots for statistics and dependency on number of fractures