FRACTURED RESERVOIR GENERATION AND SIMULATION CODES: FracGen and NFflow

BACKGROUND

Fluid flow through fractured media is becoming an ever more important part of our energy future for several reasons. Shale gas and shale oil are supplying larger amounts of our petroleum needs, and both rely on production from fractured rock. Other unconventional formations, such as tight sands, are also supplying a larger portion of our energy needs, and these also depend on flow through fractures for economical production. Understanding the tight natural fractures in rock formations that normally serve as seals and how these fractures change under varying stresses, is important when considering the storage of carbon dioxide in underlying permeable formations as a means to offset greenhouse gas emissions.

Most existing reservoir simulators are designed for flow through inter-granular permeability within intact rock, perhaps with the addition of regular grids of fractures. These simulators can handle only a small number of irregular discrete fractures, if any.

NETL has developed two software codes specifically designed to simulate reservoirs that drain through an irregular fractured network: (1) FracGen generates fracture net-works in a variety of patterns to represent reservoir flow paths, and (2) NFflow solves the material balance for compressible fluid flow inside the rock matrix and fractures of the reservoir. The codes can simulate reservoirs that are multi-layered, exhibit dip, and have variable thickness, rock porosity, and rock permeability. The reservoirs can have fractures that open and close in response to far-field stresses and fluid pressures. The matrix can have pressure adsorption of a hydro-carbon, and fractured layers can be bounded by fractured, un-fractured permeable, or impermeable layers.

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The reservoir fracture network generator, FracGen, implements three Boolean models of increasing complexity through a Monte Carlo process that samples fitted statistical distributions for various network attributes of each fracture set. Termination and intersection frequencies are controlled either implicitly or explicitly. The models can be used to account for hierarchical relations among fracture sets. Two models generate fractures in swarms. The software directly uses fracture locations, orientations, and apertures as obtained from fracture detection logs (especially FMI) of horizontal wells. It also accommodates data from outcrops, seismic surveys, and other sources, as these are used for estimating fracture and cluster lengths.

NFflow computes transient flow rates or bottom-well pressures according to user-specified pressure or rate schedules for wells. The simulator handles wells that are horizontal (including multiple laterals) or vertical and are intersected by fractures.

Dual-porosity simulators are commonly used to represent fractured reservoirs. However, networks and fractures themselves usually present large permeability anisotropies and heterogeneities across a range of scales. Thus, the scale of observation and spatial variability become critical issues in every investigation, and simple averaging, as required by conventional models, tends

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to reduce utility. NETL has found that its fractured reservoir flow simulator, NFflow, is able to increase the number of irregular fractures modeled and the speed of simulations for irregularly fractured reservoirs because of its judicious choice of modeling techniques. It directly uses the fracture network description rather than converting the network into lumped or averaged permeability parameters used in conventional simulators. One-dimensional Darcy Law models represent flow in the matrix on each side of fracture segments. The simulator was developed for dry natural gas reservoirs in a very tight matrix rock and originally accounted for only the pressure drive of the compressed fluid. Improvements recently added or currently in testing also permit the use of constant pressure boundaries around the flow region, for simulating water drives and far-field pressure drives. By incorporating equation-of-state (EoS) data on carbon dioxide in a series of importable tables, the code has been used for CO_2 sequestration research, as well.

Figure 1 shows the simulated fracture pattern for a gas field as generated by FracGen. Figure 2 shows the changes in the transmissibilities of the same fractures in response to geomechanical forces changed by production, given an assumed set of rock properties and far field stresses. Figure 3 compares NFflow's simulations for a well test to the measured data. The FracGen and NFflow codes represent a unique capability within NETL. Current research projects will further advance the existing suite of reservoir simulation codes and adapt them to the problem of natural gas production from shale and sequestration of carbon dioxide in tight formations.

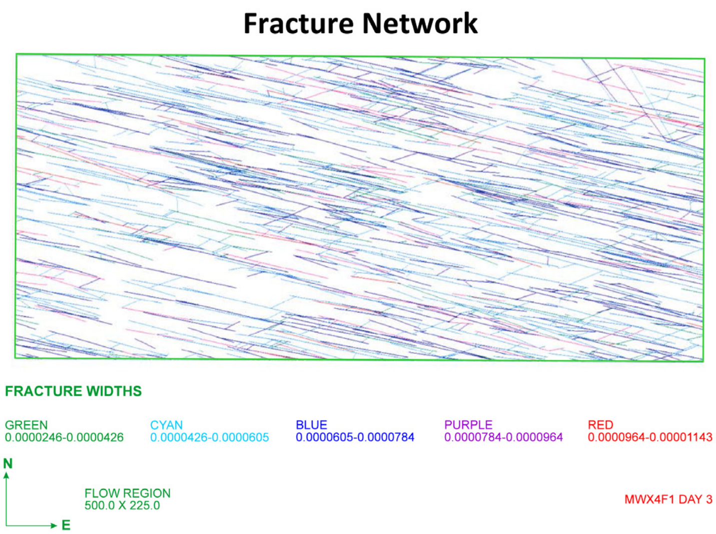

Figure 1. This multicolored fracture pattern is a realization a fracture network. The colors reference initial fracture aperture size in feet.

BENEFITS

Production of natural gas from hydraulically-fractured shales surrounding horizontal wells is a relatively recent and growing technology, and sequestration of carbon dioxide in shale reservoirs is untried. NETL's reservoir simulator was originally designed and constructed for modeling naturally fractured shale reservoirs and other "tight" fractured formations and is helpful in answering questions pertinent to exploiting this abundant fossil fuel.

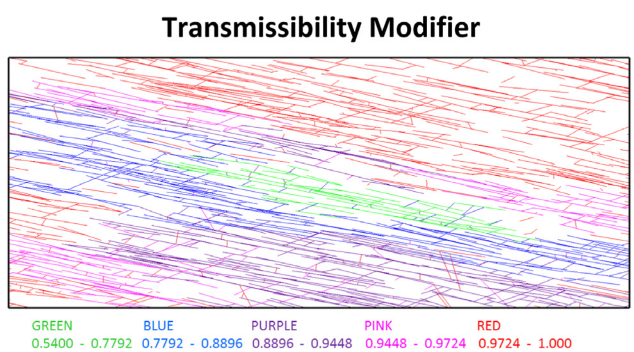

Figure 2. A snapshot after 20 days of gas production showing changes in fracture transmissibility due to induced geomechanical stresses acting on the fractures shown in Figure 1. The smaller the modifier, the smaller the fracture aperture compared to its initial size.

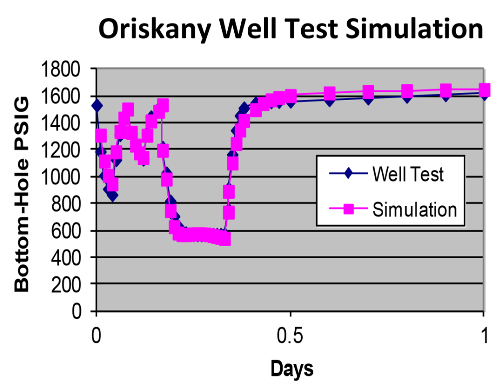

Figure 3. Measured and simulated wellhead pressure.

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