Geology and Reservoir Simulation

Background

Natural gas from shale is becoming ever more recognized as an abundant and economically viable fuel in the United States. It is composed of light hydrocarbons, so in many ways it is a more attractive fossil fuel than coal; it is easier to transport, mining is a non-issue, and it produces less carbon dioxide per unit of energy. Shales, along with siltstones and tight sandstones, are low permeability rocks, so producing natural gas from them often requires that fractures be made in the reservoir rock through "hydrofracturing," the process of using high-pressure fluids to forcefully create fractures in the rock surrounding a well. By hydrofracturing the reservoir rock, avenues are created for gas to flow from the rock to the well. If the reservoir contains some natural fractures, these may be connected to the well by the manmade fractures.

Conventional reservoir simulators are designed to represent flow through highly permeable, intact rock, where fractures offer minimal additional permeability. NETL has created a simulator for reservoirs where most of the flow occurs through fractures, rather than through intact rock. For those sorts of fractured reservoirs, NETL has found that its explicit fractured reservoir simulator composed of NFFLOW, FRACGEN and ancillary software is better able to represent realistic reservoir-scale heterogeneity and anisotropy resulting from the natural fracture network compared to conventional reservoir simulators. It directly uses descriptions of such characteristics as fracture length, orientation, and aperture as obtained from well logs, outcrop analyses, and other geological data, rather than using simple averaging to convert this data into lumped parameters used by conventional reservoir simulators.

FRACGEN generates realistic fracture patterns to represent those in most gas reservoirs. It works by implementing one of three characteristic models using a stochastic process to sample fitted statistical distributions for various fracture network attributes. NETL is adding the capability of representing fractures created by hydrofracturing and the opening and closing of fractures in response to fluid pressure and rock stresses.

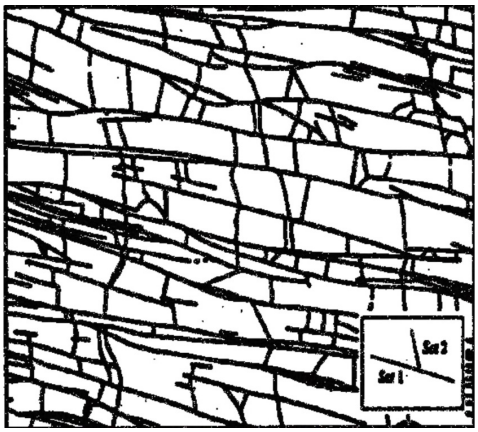

Figure 1. Example of outcrop fracture pattern (From Lorenz and Finley, 1991. Portion of image reprinted with permission of the American Association of Petroleum Geologists and Datapages, Inc.)

NFFLOW solves the material balance and flow equations for fluids in the rock and fractures of the reservoir. It computes transient flow rates or bottom hole pressures according to user-specified pressure or rate schedules. It handles wells that are horizontal (including multilaterals) or vertical and are either

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hydrofractured or intersected by natural fractures. All flow toward a well occurs through the fractures, except for drainage from the rock directly contacting the well bore. NFFLOW was developed for natural gas, but by incorporating physical data on carbon dioxide in a series of importable tables, it has been used for two-component flow and carbon sequestration research, as well.

Figure 1 shows an example of a fracture pattern in an outcrop of rock that would be typical of gas reservoirs. Figure 2 shows a simulated fracture pattern by FRACGEN for a gas reservoir in rock similar to that in the outcrop illustrated by Figure 1, but on a reservoir sized area that would be useful for modeling a well test. Figure 3 compares NFFLOW's predictions for a well test to measured data. This example is for a tight sandstone, but the reservoir simulator works equally well for shales and siltstones.

The FRACGEN and NFFLOW codes represent a unique capability within NETL's Geosciences Division for modeling the flow through tens of thousands, hundreds of thousands, even millions of fractures. Current development will further advance the existing suite of reservoir simulation codes and adapt them to other problems, such as natural gas production from organic-rich shales (where substantial adsorption and desorption effects occur) and sequestration of carbon dioxide in shale reservoirs with concurrent production of natural gas.

Benefits

Production of natural gas from shale reservoirs stimulated by hydrofracturing is a relatively recent and growing technology, and sequestration of carbon dioxide in shale reservoirs is untried. NETL's reservoir simulator is uniquely constructed to be adaptable to modeling fractured shale reservoirs and will be very helpful in answering questions pertinent to understanding these R&D areas.

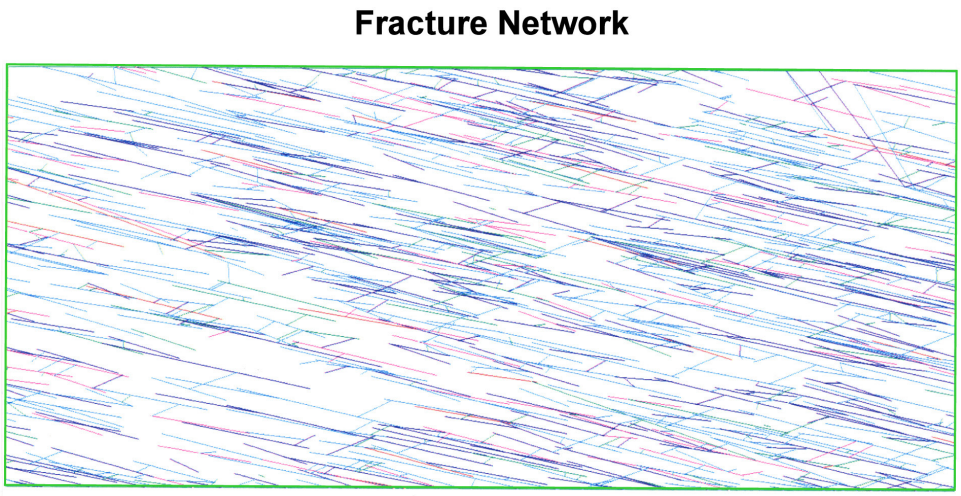

Figure 2. Stochastic realization of the fracture network in a gas reservoir near the outcrop shown in Figure 1. Outcrop data was adjusted to match core and log data on fractures in the reservoir. Colors indicate fracture aperture size in feet.

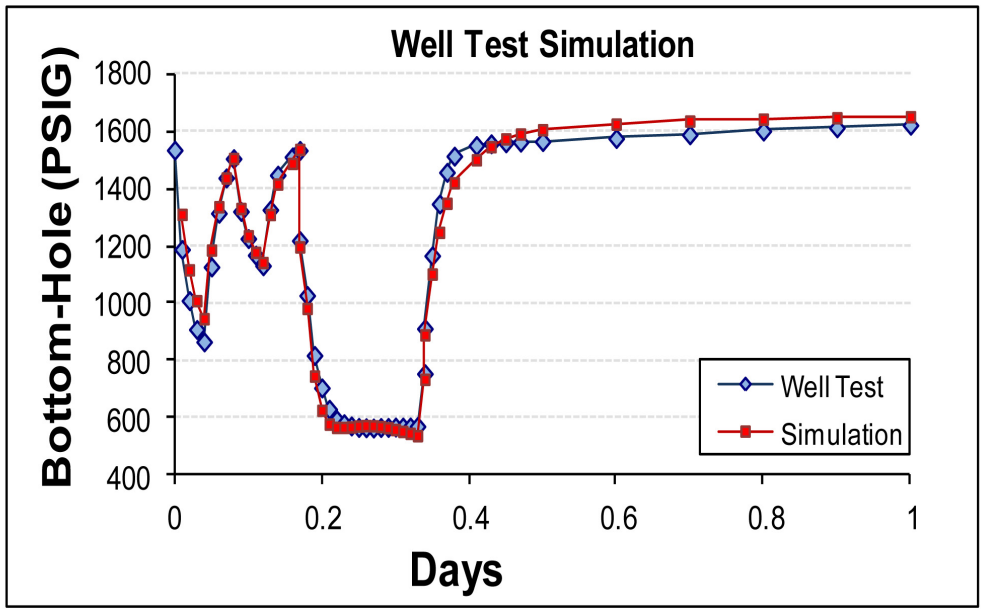

Figure 3. Sample well test history match generated by NFFLOW for a fractured gas reservoir.