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Hydraulic Fracture Predictions with a Fully Coupled Geomechanical Reservoir Simulator

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Abstract

A new geomechanical reservoir simulator (GMRS®) has been developed which combines hydraulic fracture growth, multi-phase/multi-component Darcy/non-Darcy porous flow, heat convection and conduction, solids deposition, and poroelastic/poroplastic deformation in a single application. The equations for the different mechanisms such as fracture width changes, laminar channel flow in the fracture, porous flow in the reservoir, heat convection and conduction, and poroelastic/poroplastic deformations are combined to produce an implicit fully-coupled formulation. The nonlinear system of equations is solved using a full Newton-Raphson expansion of all solution variables which enhances solution stability and allows second order convergence rates for the nonlinear iterations.

The program contains two separate criteria that one can use to model fracture propagation. Fracture growth computations can be based on critical stress intensity factors, or can use cohesive elements that exhibit strain-softening behavior. The critical stress intensity factor is based on the asymptotic stress/strain state at the tip of a fracture and is limited to linear poroelastic applications or applications where the plastic zone is small relative to the fracture length, while cohesive elements are based on energy release rates and cohesive stresses and can be used for both poroelastic and poroplastic applications. In addition to the fracture propagation logic, the program allows a dry zone to develop at the fracture tip as a natural part of the solution process. It is shown that a dry zone develops naturally at the tip of a propagating fracture for an example having a large pressure drop down the fracture.

The new geomechanical simulator is described and several examples are included to demonstrate the predictive capability of the application. Examples are also included to highlight the differences between the two fracture propagation models and to illustrate when a dry zone may be expected to develop at the fracture tip. The examples also allow one to compare the program's predictions with analytic solutions validating the fracture propagation algorithms used in the application.

Introduction

There are several different fracture simulators, both finite element (Lam and Cleary 1986; Boone and Ingraffea 1990; Papanastasiou 1997; Lujun and Settari 2007) and boundary element (Clifton and Abou-Sayed 1979; Yew and Liu 1993; Yamamoto et al. 1999; Rungamornrat et al. 2005) that predict hydraulic fracture geometry. Even though there are several fracture simulators, there are very few simulators that model complex reservoir flow, geomechanics, and fracture growth in a single application. The fracture model by Lujun and Settari uses a critical stress criterion for propagation, uses an iteratively coupled technique to combine the different physical aspects of the problem, and combines the flow in the fracture with the reservoir flow to account for fluid flow in and near the fracture. The model presented in this paper is similar in some ways to the model presented by Lujun and Settari, but allows one to use a stress intensity factor or cohesive elements for fracture propagation, uses separate grids for modeling flow in the fracture and reservoir, and fully expands the Jacobian for the full system of equations and solves all equations simultaneously in the linear solver. Modeling the fracture flow separate from the reservoir flow allows one to account for a dry zone at the fracture tip, and using a fully expanded Jacobian from an implicitly coupled system of equations provides more stability for the solution process. Numerical stability may be critical when dealing with fracture growth, cavity generation, or with any simulation that involves very small cells.