Modeling Physical Processes from Hydraulic Fracturing to Long-term Production.

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Hydraulic fracturing is a major research topic.for recovering oil and gas from tight gas and shale plays. Many energy experts feel it is pivotal in meeting a continually growing energy demand. Using slick water and proppant, fracking creates fractures from a wellbore drilled into reservoir rock formations. There are economic benefits and costs of extracting vast amounts of formerly inaccessible hydrocarbons. In addition, there are environmental benefits of producing natural gas, much of which is produced in the United States from fracking making the country nearly energy independent. Efficiency of fracturing jobs depends on the interaction between hydraulic (induced) and naturally occurring discrete fractures. Optimizing production includes determining location of horizontal wells and fracture patterns and spacing. A quantitative assessment of hydraulic fracturing jobs relies upon accurate predictions of fracture growth during slick water injection for single and multistage fracturing scenarios. Opponents to fracking point to environmental impacts such as contamination of ground water, risks to air quality, migration of fracturing chemical and surface contamination from spills, to name a few. For these reasons, hydraulic fracturing is being heavily scrutinized. Thus there is an essential need for accurate and robust mathematical and computational models for treating fluid field fractures surrounded by a poroelastic medium. In addition, It is important to consistently model the underlying physical processes from hydraulic fracturing to long-term production.

In this presentation we discuss fracture propagation using a phase field approach and present a technique for coupling this model to the fractured poroelastic reservoir simulator IPARS developed at The University of Texas at Austin Center for Subsurface Modeling.. The proposed coupling approach can be adapted to existing reservoir simulators.

Variational approaches (Francfort and Marigo (1998); Bourdin et al. (2008)) and a thermodynamically consistent phase field formulation (C. Miehe (2010)) have been employed in solid mechanics. Our approach (Mikelic et al. (2013a,b)) is based upon C. Miehe (2010) with an extension to porous media applications where solids (geomechanics) interact with fluids. To develop a phase-field formulation for such applications, geomechanics and porous media flows are decoupled using fixed-stress splitting (Settari and Walters (2001); Mikelic and Wheeler (2012)). With this methodology, modeling and simulations of hydraulic fractures in poroelasticity have been considered (Mikelic et al. (2013a,b, 2014b); Wheeler et al. (2014); Mikelic et al. (2014a); Wick et al. (2014)). We presents two and three dimensional numerical tests to benchmark, compare and demonstrate the predictive capabilities of the fracture propagation model as well as the proposed coupling scheme. Our computations use he deal2 framework with hexahedral mesh.

Major advantages of using phase- field modeling for crack propagation are fourfold: First, and most important, the model is easy to implement and uses a fixed-grid topology in which remeshing for resolving the exact fracture location is avoided. Second, fracture nucleation, propagation, kinking, and curvilinear path are intrinsically determined. This avoids computational overheads associated with post-processing of quantities such as stress intensity factors. Third, we can easily handle large fracture networks since complex phenomena of joining and branching does not require keeping track of fracture interfaces. Fourth, modeling crack growth in heterogeneous media does not require special treatment.
Here however, the length-scale parameter should be chosen accordingly. Additionally, the crack opening displacement (fracture aperture) can be calculated using the phase- field function.

For treating long-term production we first describe a two-phase flow model.. We use hexahedral grids with a multipoint flux mixed finite element method (MFMFE) scheme which allows non-planar fractures and accurate computation of a locally mass-conservative flow problem. We resolve the flow equations for both the fractures and reservoir in a coupled manner. This is achieved by assuming a lubrication equation inside the fractures and a multiphase Darcy law for the reservoir. A fixed stress splitting scheme for the geomechanics effects in a reservoir has been extended to include fractures where the permeabilities of the fracture are functions of the deformations.

We briefly describe the proposed coupling method for translating fracture location, geometry and width information between the phase-field crack propagation model and the production reservoir code. The use of hexahedral elements for spatial discretization in both models allows translation of fracture location and variables from one model to another. The phase-field with crack growth and localized flow is used as a pre-processor step for the fractured reservoir flow. This results in a forward solution with the pertinent fracture geometry and width translated at the end of the propagation. We consider phase- field as an independent module that can be coupled to other codes. This assumes hydraulic fracture growth to be a local or near well bore phenomenon which is not affected by far-field reservoir complexities such as reservoir boundaries, faults and barriers. Under this assumption, the two processes: hydraulic fracturing and later production are decoupled. Thus a local flow problem with appropriate boundary conditions is solved to compute a local pressure field during fracture propagation. This forward coupling is computationally inexpensive and adequately captures local flow field variations effecting fracture growth. Another advantage is that the phase field crack propagation model generates fracture growth information as a standalone module. The spatial and temporal scales associated with fracture growth and later production from a hydraulically fractured reservoir are widely different. Therefore, it is reasonable to treat the two processes separately. Computational examples for both production and coupling are provided.

This work has been done in collaboration with Andro Mikelic, Thomas Wick, Gurpreet Singh, and Sanghyun Lee.