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Three-dimensional numerical simulation of transient compressible flows in fractured formations

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1 Introduction

This communication addresses single phase, slightly compressible flow through fractured porous media. A very general 3d numerical model based on a discrete fracture representation is proposed, together with a set of applications.
This tool can be applied for the interpretation of well test data, to quantify the characteristics of a reservoir, or conversely, to optimize the design of a producing well, given the reservoir characteristics.
2 Governing equations and numerical model
The fractured formation can be represented as an arbitrary set of fractures embedded in a porous matrix. The flow of a slightly compressible fluid is governed in the matrix by Darcy's law and the continuity equation, with source terms to represent the exchanges with the wells. A 2d counterpart of the same equations including exchanges with the surrounding matrix applies in the fractures. A particular attention has been given to a precise evaluation of these exchanges.
The head pressure or the total pumping rate can be prescribed at the wells. Various conditions can be applied at the domain boundaries, such as constant pressure or no flow.
The rock matrix is meshed by tetrahedral volume elements and the fractures by triangular surface elements. All the properties such as permeability, porosity of pressure diffusivity can be prescribed on a per element basis.
The pressure is evaluated at the vertices of the surface and volume elements. The discretized equations are obtained by integration of the balance equations over control volumes around the mesh points. Time derivatives are discretized to first order, in a fully implicit formulation. A biconjugate gradient algorithm is used in order to solve the resulting algebraic equations.

3 Results

The emphasis of the talk is put on three sets of applications in fractured aquifers.
In the first one, pressure drawdown well tests in closed aquifers are simulated, for complex model situations. First, simulations are run when a well crosses a periodic set of parallel fractures. Then, one considers media where fractures are plane hexagons, randomly located and oriented in space. The results are analyzed in terms of the well pressure as a function of time and of its derivative with respect to the logarithm of time. Several successive transient and quasi-steady regimes are distinguished, dominated by the flow through the fractures at early time and in the matrix in a later stage. As a rule, the same typical flow regimes appear in the drawdown curves for wells in regularly or randomly fractured media, although some features are blurred in the latter case because of the broader range of length and time scales.
The second application is a complete field-scale simulation of the production history in an aquifer with transient boundary conditions and multiple wells with varying flow rates. The aquifer contains faults of irregular shapes and size, and a system of more than 700 small fractures with various hydraulic properties. The well flow rate history was used as inputs for the simulations and the observed well pressures were compared with the simulation results.
Finally, the fractured aquifer in the Poitiers Hydrological Experimental Site (SEH) is studied. The 8x8x0.1 km3 simulation domain contains more than 30 vertical wells and a 500x500x100m3 fractured zone with four families of fractures whose orientations follow the regional trends. Improvements have been introduced for a better description of the fracture/matrix transfers during fast transients. Illustrative results for two-well pumping tests are presented.