Abstract

Discrete fracture network flow simulators are arguably the best platforms for T&P calculations, geochemistry, and mechanical behavior modeling along natural fracture flow pathways in unconventional reservoirs. Thus, NETL’s discrete fracture reservoir simulator, NFflow, is being modified to simulate non-isotherm conditions. The fracture segments that were previously represented as single elements are now subdivided both vertically and horizontally to model heat transport within the fractures. The rock matrix surrounding each fracture segment that was previously modelled by a one-dimensional model has been replaced by a three-dimensional model, which is also extended vertically to include rock above and below the reservoir layer.

The work is being done in stages. The first stage has included the new gridding algorithms for the fractures and surrounding rock and the development of an indexing scheme capable of describing the new geometric complexity. An energy balance was added that describes the convective energy transport in the fractures, the conductive transport in the rock matrix both horizontally and vertically, and the exchange of energy between the rock and fluid phases. In the first stage of the project the thermodynamics is restricted to a liquid as the fluid phase and the fluid flow is restricted to the fractures. In a later stage the thermodynamics will be extended to gases and supercritical fluids and the flow equations extended to include fluid exchange between the fractures and rock matrix.

 NFflow is intended for use on personal computers, rather than super computers, making it more widely available to all potential users.

Definitions

\[ T = \text{fluid temperature} \]
\[ 0 = \text{rock temperature} \]
\[ P = \text{pressure} \]
\[ \rho = \text{mass density} \]
\[ \mu = \text{viscosity} \]
\[ z = \text{compressibility factor} \]
\[ b = \text{fracture aperture} \]
\[ \phi = \text{void fraction} \]
\[ k_v = \text{thermal conductivity of rock} \]
\[ k_r = \frac{\mu^2}{12} = \text{transmissibility of fracture} \]

\[ p_s(1) = \text{liquid heat capacity} \]
\[ p_s(1)m = \text{effective heat capacity} \]
\[ \nu = \text{velocity vector} \]
\[ u \& w = \text{superficial fluid velocity. x-direction & y-direction} \]
\[ Q_s = \text{mass flow rate through a node in the direction l positive away from node} \]
\[ q_i = \text{energy flow rate from the direction l positive into the fracture midpoint} \]
\[ \ddot{u} = \text{specific internal energy} \]

Pre-existing Model

Fracture Network

The Rock Matrix

- Inter-granular flow is modeled with Darcy’s Law
- 1-D approximation: only communicates with adjacent fracture segment
- Simplified for effective volume
- Each of these problems is solved independently

Flow Path Intersections

- Zero-volume, no accumulation term
- Fracture flow modeled as flow between two parallel plates
- Reduce problem by calculating the pseudo-potential at these points

Segment Mid-points

- Mass balance is derived from the continuity equation using the above expression for the pseudo-potential
- The mass flux is evaluated at the cell boundary using the pseudopotential and uses the boundary conditions

The Model

- Solve for Pseudo-Potentials rather than pressure to reduce non-linearity of the mass balance problem
- Newton-Raphson method used on Non-linear discrete problem
- Linear problem solved for used Thomas algorithm for matrix solution, SOR for flow path intersection

Problem Becomes Much More Difficult

- Added equations for energy.
- Domain for energy problem much larger than domain for mass flow problem.
- Because equivalent volume problem has expanded to three dimensions, previous decomposition not possible. Variables at all locations must be solved simultaneously.
- Pseudo-potential is now a function of temperature, and a new solution technique is necessary. The linear equations lose their simple form.
- The number of solution variables increases by one or two orders of magnitude.
- But the linear equations still have the form where the energy balance is restricted to a liquid as the fluid phase and the fluid flow is restricted to the fractures.

Fracture Segments, Nodes, & Matrix Volumes

Matrix to Fracture Flows as Discretized

- Mass flux according to Darcy’s Law: \[ \dot{m} = -k \cdot (\epsilon \cdot P + \rho \nu) \]
- Mass balance is derived from the continuity equation using the above expression for the mass flux \[ \dot{m} = -\epsilon \cdot (\epsilon \cdot P + \rho \nu) \]
- Pseudopotential: \[ \Phi(p) = \frac{q}{\epsilon \cdot P} dP \]
- The equations are solved sequentially with the mass fluxes first computed and then used in the advection equations, \[ \dot{m} = \rho \nu, \ \dot{u} = \frac{q}{\epsilon \cdot P} \]

Entire Domain Communicates with Fracture

- Conductive Heat Transfer: \[ \frac{\partial}{\partial t} \left( \frac{1}{\rho C_p} \right) = \frac{k_p}{\epsilon} \cdot \theta \]
- Previous one-dimensional problems have expanded to three-dimensional problems
- No longer possible to decompose and simplify the problem as previously