MODELING OF GEOMECHANICS IN NATURALLY FRACTURED RESERVOIRS

M. Bagheri, SPE, and A. Settari, SPE, U. of Calgary

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Presenter : Xiu-Yi Lei
Adviser : Jia-Jyun Dong
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DEFORMATION MECHANICS OF A SINGLE FRACTURE

- fracture normal deformation:
  \[
  \sigma_n = \frac{\Delta v}{a - b \Delta v}
  \]

- Maximum closure:
  \[
  \Delta v_{\text{max}} = \frac{a}{b}
  \]

- Normal stiffness:
  \[
  k_n = \frac{d \sigma_n}{d \Delta v} = k_n = \frac{\partial \sigma_n}{\partial \Delta v} = \frac{1}{a \left(1 - \frac{b}{a} \Delta v\right)^2}
  \]

  \[
  k_n = \frac{k_{ni}}{\left(1 - \frac{\Delta v}{\Delta v_{\text{max}}}ight)^2}
  \]

  Change with volume

  (Bandis et al. 1983)
The Equivalent continuum model’s behavior contain the behavior of intact rock and discontinuities.

\[
\Delta \varepsilon_{ij} = \Delta \varepsilon_{ij}^I + \Delta \varepsilon_{ij}^J
\]

\[
\Delta \varepsilon_{ij}^I = C_{ijkl}^I \Delta \sigma_{kl}
\]

\[
\Delta \varepsilon_{ij}^J = C_{ijkl}^J \Delta \sigma_{kl}
\]
Initial aperture of each fracture set in a grid block is calculated using Bandis et al. technique.

- Hysteresis in fracture deformation is neglected.
- Calculation of fracture permeability uses cubic law multiplied by a correction factor.
Dynamic Coupling

- Matrix and fracture porosity and pressure are transferred to the geomechanics module in each geomechanical iteration loop to build a new continuum pore pressure.
- New fracture normal stiffness and flow properties are calculated in each geomechanical iteration loop using new transferred fracture pressure from the flow model.

**Diagram:**

- **Continuum pore pressure** → **Normal stiffness & flow properties** → **Equivalent constitutive matrix** → **Stress & strain**

**Geomechanics Module**
1. Form continuum pore pressure
2. Calc. $b_r, \phi_r, k_r, k_n$ using $p^{nf}, \sigma^{nf-1}$
3. Build equivalent constitutive matrix
4. Calculate $\sigma_r, \epsilon_r$
5. Build rock-only constitutive matrix
6. $\epsilon_{vm} = f(\sigma_{ng}, p_{ng})$

**Update porosity**
$\phi_0 = \phi_m(p_m, T, a)$

**Converged?**
- **NO**
  - Update properties $\phi = \phi_d(p_d, a), k = k_d(p_d, a)$
- **YES**
injection water at the rate of 200 bbl/day produces oil at the rate of 210 bbl/day
Fig. 16- Fracture aperture variation with time and effective stress
CONCLUSION

- iteratively coupled geomechanics and dual porosity reservoir simulator has been successfully developed which is able to model fracture permeability in a dynamic fashion.

- Dynamic treatment of fracture permeability does indeed require a coupled formulation, since stress is a key parameter controlling fracture deformation.

- modeling fracture permeability dynamically leads to:
  - Large changes in fracture permeability
  - permeability anisotropy
  - Steeper pressure gradient in depletion
FUTURE WORK

- Consider the effect of pore water pressure in fractures
  - Mechanical behavior
  - Hydraulic behavior
- To know the change with time
THANKS!
**EQUIVALENT MODEL**

\[
\Delta \varepsilon_{ij} = \Delta \varepsilon_{ij}^I + \Delta \varepsilon_{ij}^J
\]

\[
\Delta \varepsilon_{ij}^I = C_{ijkl}^I \Delta \sigma_{kl}
\]

\[
\Delta \varepsilon_{ij}^J = C_{ijkl}^J \Delta \sigma_{kl}
\]

\[
\Delta \delta_{I} = D_{ij} \Delta \tau_{j}
\]

\[
\Delta \tau_{j} = \Delta \sigma_{ij} n_{i}
\]

\[
\sigma_{ij} \Delta \varepsilon_{ij}^f = \frac{1}{V} \sum_{f=1}^{M} \tau_{j}^f \Delta \delta_{j}^f A_{j}^f
\]

\[
C_{ijkl}^J = \sum_{f=1}^{M} n_{i}^{f} L_{ij}^{f} D_{jkl}^{f} L_{i}^{f} n_{k}^{f} \frac{1}{S_{j}^{f}}
\]

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