Geomechanical Effects on Porosity and Permeability

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Porosity changes come from
- pore pressure change
- stress change
- thermal expansion

Porosity changes lead to Permeability changes

Tran, D., Settari, A., Nghiem, L., 2004, New Iterative Coupling Between a Reservoir Simulator and a Geomechanics Module, *SPE Journal*, Vol. 9, No. 3.

$$\phi^* = \phi^*(p, T, \underbrace{S_m}_{= \frac{1}{3}(S_1 + S_2 + S_3)})$$

Using Taylor's series

$$f(x+h) = f(x) + \frac{h}{1!}f'(x) + \frac{h^2}{2!}f''(x) + \cdots$$

$$\phi^*_n = \phi^*(p, T, S_m)$$

$$\phi^*_{n+1} = \phi^*(p + \Delta p, T + \Delta T, S_m + \Delta S_m)$$

$$= \phi^*_n + \left(\frac{\partial \phi^*}{\partial p}\right)_{S_m, T} \Delta p + \left(\frac{\partial \phi^*}{\partial T}\right)_{p, S_m} \Delta T + \left(\frac{\partial \phi^*}{\partial S_m}\right)_{p, T} \delta S_m$$

$$+ O^2(p, T, S_m)$$

$\Delta\phi^*$ caused by pore pressure change

$\Delta\phi^*$ caused by temperature change

$\Delta\phi^*$ caused by total stress change

P change → S change

If S is fixed, p change leads to only σ change

$$\left(\frac{\partial \phi^*}{\partial p}\right)_{S_m, T} = \left[\frac{\partial \left(\frac{V_p}{V_b^0}\right)}{\partial p}\right]_{S_m, T} = \frac{1}{V_b^0}\left(\frac{\partial V_p}{\partial p}\right)_{S_m, T}$$

$$\left(\frac{\partial \phi^*}{\partial S_m}\right)_{p, T} = \left[\frac{\partial \left(\frac{V_p}{V_b^0}\right)}{\partial S_m}\right]_{p, T} = \frac{1}{V_b^0}\left(\frac{\partial V_p}{\partial S_m}\right)_{p, T}$$

$$\left(\frac{\partial \phi^*}{\partial T}\right)_{p, S_m} = \frac{1}{V_b^0}\left(\frac{\partial V_p}{\partial T}\right)_{p, S_m}$$

$$dV_p = \left(\frac{\partial V_p}{\cdot}\right) dp + \left(\frac{\partial V_p}{\cdot}\right) dS_m + \left(\frac{\partial V_p}{\cdot}\right) dT$$

$$dV_p = \left(\frac{\partial V_p}{\partial p}\right)_{S_m,T} dp + \left(\frac{\partial V_p}{\partial S_m}\right)_{p,T} dS_m + \left(\frac{\partial V_p}{\partial T}\right)_{p,S_m} dT$$

$$dV_b = \left(\frac{\partial V_b}{\partial p}\right)_{S_m,T} dp + \left(\frac{\partial V_b}{\partial S_m}\right)_{p,T} dS_m + \left(\frac{\partial V_b}{\partial T}\right)_{p,S_m} dT$$

$$\left(\frac{\partial V_p}{\partial p}\right)_{S_m,T} = \frac{dV_p}{dp} - \left(\frac{\partial V_p}{\partial S_m}\right)_{p,T} \frac{dS_m}{dp} - \left(\frac{\partial V_p}{\partial T}\right)_{p,S_m} \frac{dT}{dp}$$

$$\phi^*_{n+1} = \phi^*_n + \underbrace{\left(\frac{\partial \phi^*}{\partial p}\right)_{S_m,T}}\Delta p + \left(\frac{\partial \phi^*}{\partial T}\right)_{p,S_m} \Delta T + \left(\frac{\partial \phi^*}{\partial S_m}\right)_{p,T} \Delta S_m$$

$$= \frac{1}{V_b^0}\left(\frac{\partial V_p}{\partial p}\right)_{S_m,T} \Delta p = \frac{1}{V_b^0}\frac{dV_p}{dp}\Delta p - \frac{1}{V_b^0}\left(\frac{\partial V_p}{\partial S_m}\right)_{p,T}\frac{dS_m}{dp}\Delta p - \frac{1}{V_b^0}\left(\frac{\partial V_p}{\partial T}\right)_{p,S_m}\frac{dT}{dp}\Delta p$$

$$= \phi^*_n + \frac{1}{V_b^0}\frac{dV_p}{dp}\Delta p + \frac{1}{V_b^0}\left(\frac{\partial V_p}{\partial S_m}\right)_{p,T}\left[\Delta S_m - \frac{dS_m}{dp}\Delta p\right] + \frac{1}{V_b^0}\left(\frac{\partial V_p}{\partial T}\right)_{p,S_m}\left[\Delta T - \frac{dT}{dp}\Delta p\right]$$

$$\phi^*_{n+1} = \phi^*_n + \phi_0\left[C_p \Delta p - C_T \Delta T\right] - \left[C_\phi(1-\varepsilon_v^n) + C_b \phi_n\right]\Delta S_m$$

$$C_p = \frac{C_\phi(1-\varepsilon_v^n) + C(C_b - C_s)\phi_n}{\phi_0}$$

$$C_T = -\frac{\phi_n}{\phi_0}\beta$$

$$C_b = \frac{1}{K}$$

C_s = solid grain compressibility

$$C_\phi = C_b(1-\phi_n) - C_s$$

* $\Delta S_m = a_1 \Delta p + a_2 \Delta T$

i) bilateral constraint move vertically

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i) bilateral constraint, move vertically

$\epsilon_{11} = \epsilon_{22} = 0$ at the lateral boundary

$\sigma_{33} = 0$ at the top

$$a_1 = \frac{2}{9} \frac{E}{(1-\nu)} (C_b - C_s) \Delta p$$

$$a_2 = \frac{2}{9} \frac{E}{(1-\nu)} \beta \Delta T$$

ii) Other constraints

Refer to Tran et al., 2004.

* Permeability

$$k = k_0 e^{-A(\sigma - \sigma_0)}$$