The Role of Counter-Current Flow in the Migration of CO_2 in Saline Aquifers

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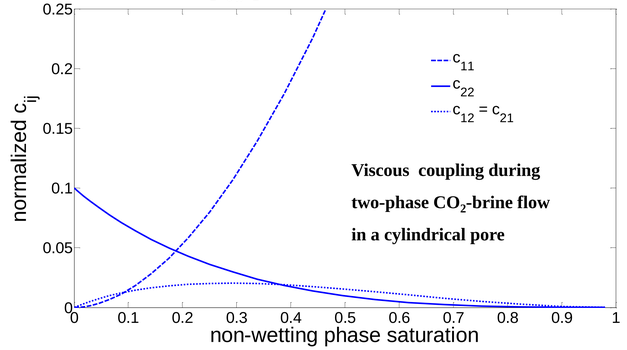
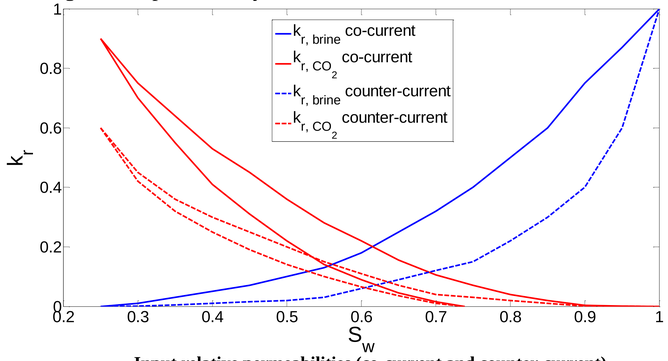
Introduction:

Viscous coupling results in a reduction of CO_2/brine relative permeability during counter-current flow relative to what is measured in co-current flow experiments. The significance of the viscous coupling for two-phase flow in a cylindrical pore can be illustrated via a generalized form of Darcy's equation:

$$\begin{bmatrix} Q_{nw} \\ Q_w \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix} \cdot \frac{\partial}{\partial x} \begin{bmatrix} p_{nw} \\ p_w \end{bmatrix}$$



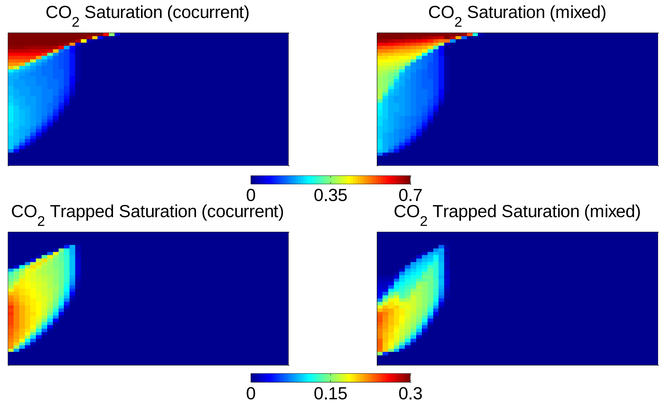
To represent this effect in numerical calculations, we use two sets of bounding relative permeability curves (1: co-current and 2: counter-current) in a modified version of GPRS. The relative permeability of each phase is calculated from the velocity of both phases in each cell. We call this model the "mixed" model, as opposed to the co-current model (current standard) that relies one a single set of bounding relative permeability functions.



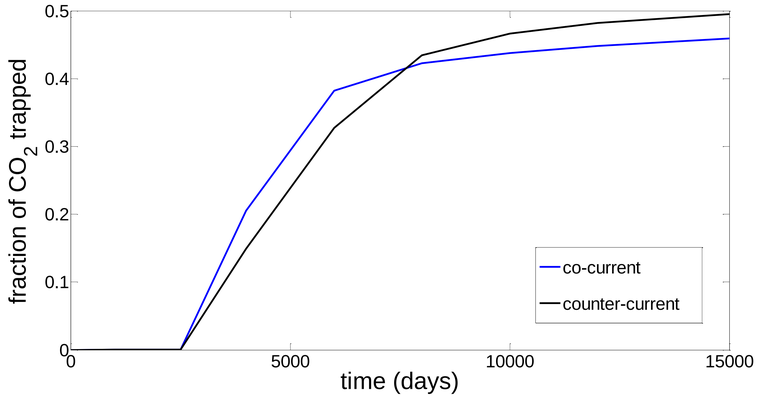
Input relative permeabilities (co-current and counter-current)

Example I: 2D Simulation of CO_2 injection

- Aquifer: 5000*500 ft (50*40 cells); Permeability: k_x = 50 mD, k_z = 20 mD
- Injection (left): 11K tonne CO_2/100ft/yr; Open hydrostatic boundary (right)



CO_2 saturation profile in the co-current (left) and mixed (right) models after 6000 days



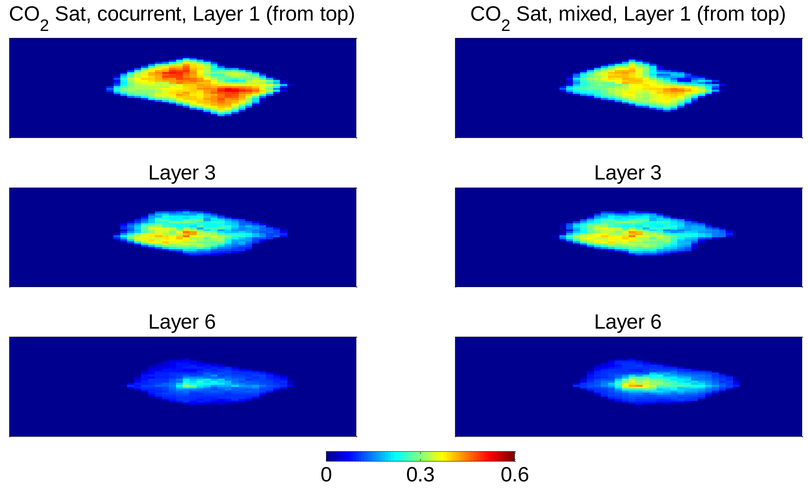
Comparison of trapped fraction of CO_2 from co-current and mixed model

Observations:

- No change in pressures (cells and bottom-hole pressures) and injection and production rates
- Negligible decrease in time step size and little increase in total simulation time

Example II: 3D Simulation of CO_2 injection

- Aquifer: 5000*5000*500 ft (100*100*10 cells)
- Permeability: Heterogeneous ($k_{h, avg}$~90 mD, $k_{v, avg}$~9 mD)
- Injection well in the middle of the domain: 0.22 Mt/yr for 2500 days
- Open and hydrostatic boundaries (simulated via production wells)



CO_2 saturation in the co-current (left) and mixed (right) models after 10000 days

Conclusions:

For accurate modeling and simulation of CO_2 injection into saline aquifers, the effect of flow transitions from co-current to counter-current (and vice versa) must be considered. This will modify the relative permeability functions (viscous coupling) and affect dynamics of plume migration and CO_2 entrapment.

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