Storage of CO_2 in saline aquifers: effects of gravity, viscous, and capillary forces on amount and timing of trapping

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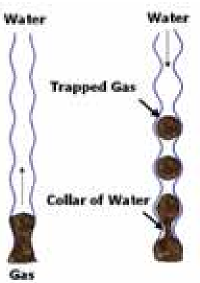
Simulation approach

Motivation:

CO_2 storage in aquifers is one of many methods by which CO_2 emissions may be reduced. In this study, we investigate how aquifer properties and different injection schemes impact both the quantity and the rate of injected CO_2 becoming immobilized via residual trapping. Three parameters are varied in order to investigate the trapping phenomenon. First, CO_2 is injected into aquifers under varying ratios of gravity to viscous forces (N_{gv}). Second, we study how the rate and the amount of the injected CO_2 varies with the dip angle of the aquifer. Last, an alternative injection scheme is proposed to encourage the immobilization of CO_2.

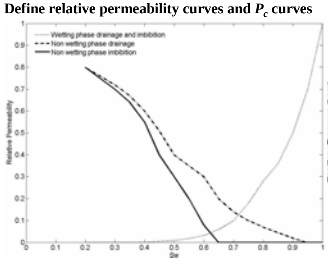


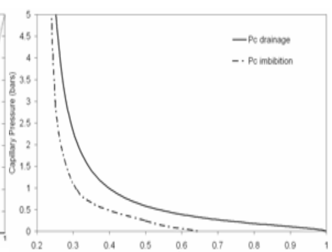
Physics of Capillary Trapping:

- Hysteresis effects are observed in both relative permeability and capillary pressure (P_c).
- Trapping occurs when gas saturations decline.
- The amount trapped depends on the maximum gas saturation before the saturation begins to decline.
- Once the injected gas is snapped off, the trapped gas cannot move unless:
  - A significant viscous force displaces the trapped gas
  - The gas is reconnected
- The trapped gas can dissolve in the surrounding brine leading to permanent storage.

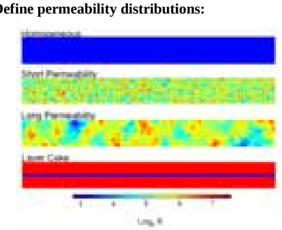
Simulation Approach:

Define relative permeability curves and P_c curves





Define permeability distributions:



Aquifer setting:

$$N_{gv} = \frac{k_v L \Delta\rho g}{H u \mu_{brine}}$$

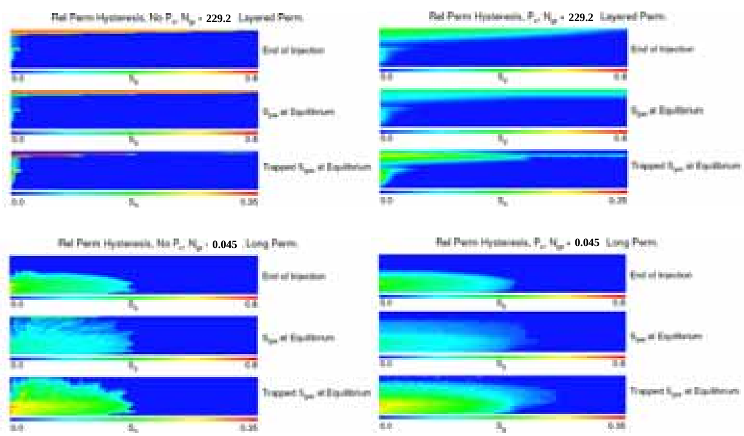
Each aquifer model is associated with a gravity number, N_{gv}, as defined in the equation above.

N_{gv} was varied by altering injection rates and k_v/k_h ratios.

Results

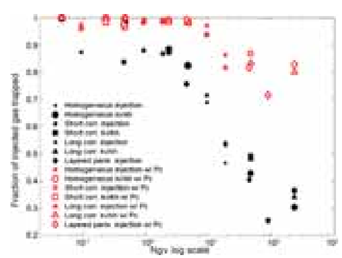
Saturation profiles for high and low N_{gv}:

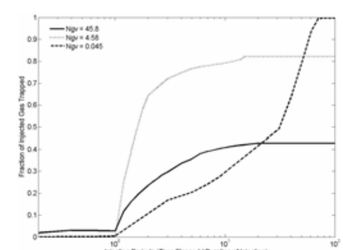
Without P_c — With P_c



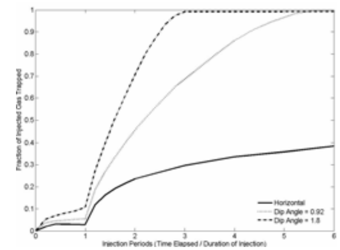
Fraction of injected gas trapped vs. N_{gv}:

- Fraction of injected gas trapped decreases as the gravity number of the system increases.
- As seen in the saturation profiles above, systems with high gravity numbers lead to the formation of strong gravity tongues.
- In the absence of any dip, the saturations in the gravity tongue cannot be reduced, and thus remain mobile.
- The addition of capillary pressure shows that a greater volume of aquifer is contacted before flow reversal, leading to a higher trapped saturation amount.
- High gravity number systems trap less of the injected gas, but do so more quickly, compared to low gravity number systems that trap more but over a longer time scale.



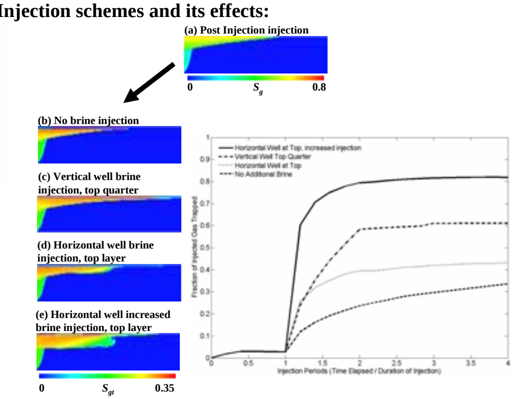


Dip angle and its effects:



Only a minor dip angle shows significant increase in both the rate and the amount of CO_2 trapped

Injection schemes and its effects:



Conclusion and future work:

- High ratio of gravity to viscous forces causes a gravity tongue to form, which limits trapping
- The presence of capillary pressure effects enhances trapping
- High gravity number systems trap less, but do so relatively quickly
- Low gravity number systems trap more, but more slowly
- Larger dip angles enhance CO_2 trapping efficiency
- Carefully engineered injection schemes can increase trapping
- Other injection schemes besides those considered in this study must be explored.

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