Advances in Water Resources 96 (2016) 225–236

Contents lists available at ScienceDirect

Advances in Water Resources

journal homepage: www.elsevier.com/locate/advwatres

# Comparison of $CO_2$ trapping in highly heterogeneous reservoirs with Brooks-Corey and van Genuchten type capillary pressure curves

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ARTICLE INFO

*Article history:*
Received 11 January 2016
Revised 30 July 2016
Accepted 31 July 2016
Available online 1 August 2016

*Keywords:*
$CO_2$ geosequestration
Capillary trapping
Brooks-Corey
van Genuchten
Heterogeneity
Sedimentary architecture

ABSTRACT

Geological heterogeneities affect the dynamics of carbon dioxide ($CO_2$) plumes in subsurface environments in important ways. Previously, we showed how the dynamics of $CO_2$ plumes are influenced by the multiscaled sedimentary architecture in deep brine fluvial-type reservoirs. The results confirm that representing small-scale features and the corresponding heterogeneity in saturation functions, along with hysteresis in saturation functions, are all critical to understanding capillary trapping processes. Here, we show that when heterogeneity and hysteresis are represented, the two conventional approaches for defining saturation functions, Brooks-Corey and van Genuchten, represent fundamentally different physical systems. The Brooks-Corey approach represents heterogeneity in entry pressures, and leads to trapping by capillary pinning. The van Genuchten approach represents a network of pores transporting the nonwetting fluid, across rock types, with negligible capillary entry pressure, and leads to capillary retardation. These differences significantly affect the large-scale characteristics of $CO_2$ plumes (i.e., their mass, shape, and position).



## 1. Introduction

The idea of reducing atmospheric carbon dioxide ($CO_2$) by capturing $CO_2$ from emission streams and injecting and permanently sequestering it the Earth's crust has been examined for decades (Gale et al., 2015). Multiple $CO_2$ sequestration research and demonstration projects have been operating worldwide since 1972. The critical question is whether injected $CO_2$ can be permanently stored in deep sedimentary basins without affecting groundwater quality? To answer this question detailed modeling of the migration and distribution of injected $CO_2$ in the subsurface is required.

Various processes may trap supercritical $CO_2$ ($CO_2$ hereafter) emplaced in deep brine reservoirs, including shorter-term physical trapping (0–10 years), intermediate-term dissolution in brine (0–1000 years), and longer-term mineralization (100 years–million years). Here, the focus is on the processes of physical trapping and dissolution taking place within the reservoir before a plume reaches caprock, and not on structural trapping by caprock at the top of the reservoir, or on mineralization.

A large body of experimental, theoretical, and numerical research now shows that capillary trapping has a primary impact on the distribution of $CO_2$ within the permeable sections of the reservoir, and field observations now confirm the formation and stability of capillary trapped $CO_2$ there, e.g., Krevor et al. (2015). There are two main capillary trapping processes:

(1) Carbon dioxide bubbles are trapped within pore spaces because of "snap-off" (Fig. 1a), a process in which counter-imbibition of brine (the wetting fluid) behind the advancing plume, preferentially through smaller pores and pore throats, traps $CO_2$ bubbles within the intervening pore bodies (e.g., Hunt et al., 1988; Wildenschild et al., 2011; Iglauer et al., 2011). In conventional modeling approaches, this process is reflected in hysteresis in the constitutive relationship between relative permeability and phase saturation (e.g., Juanes et al., 2006; Spiteri et al., 2008; Joekar-Niasar et al., 2013). Snap-off trapping allows $CO_2$ to be distributed with a larger surface area, and thus enhances solution trapping. The process is lessened if the medium is not strongly water wet; however, in data reviewed by Iglauer et al. (2015), most reservoir rocks exhibit water-wet behaviour, and the water-wet medium assumption is common in studies of capillary trapping. Altundas et al. (2011)

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http://dx.doi.org/10.1016/j.advwatres.2016.07.022

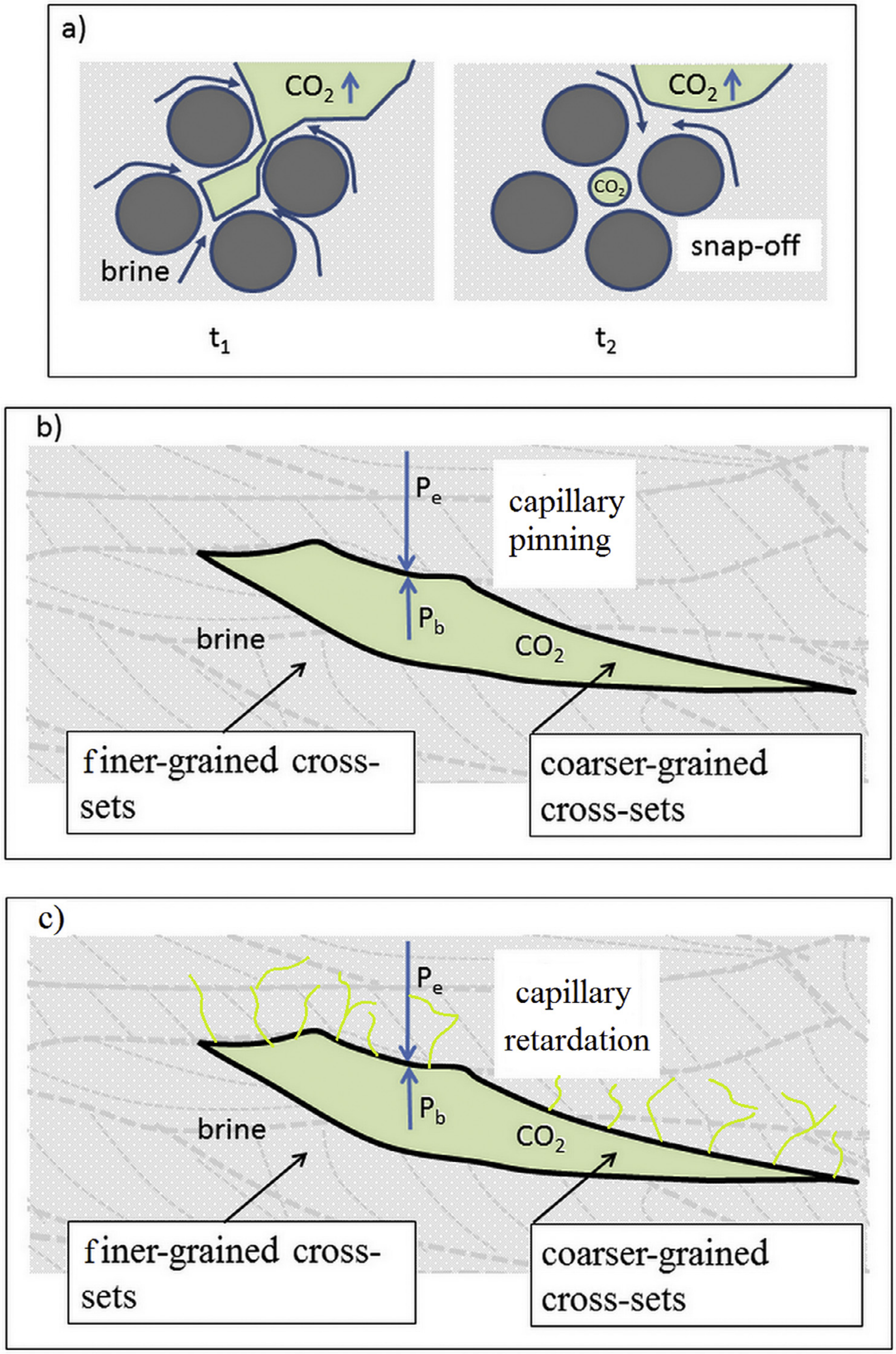


**Fig. 1.** (a) Snap-off trapping: Counter-imbibition of brine (the wetting fluid) behind the advancing plume occurs preferentially through smaller pores and pore throats, trapping $CO_2$ bubbles within the intervening pore bodies (e.g., Hunt et al., 1988; Wildenschild et al., 2011; Iglauer et al., 2011). (b) Capillary pinning: $CO_2$ is pinned below local contacts between an underlying rock type with larger pores and an overlying rock type with smaller pores and thus larger entry pressure. This occurs where the entry pressure ($P_e$) of the FG rock exceeds the buoyant pressure ($P_b$) of $CO_2$ in the CG rock (e.g., Bryant et al., 2006; Ide et al., 2007; Gershenzon et al., 2014, 2015; Saadatpoor et al., 2009; Zhou et al., 2010); this effect is quasi-permanent. (c) Capillary retardation: a transient pinning effect in which $CO_2$ preferentially enters regions with larger pores during injection, and leaks through network of pores with negligibly small capillary pressure in the overlying, finer-grained rock. Increase in $CO_2$ saturation in the finer grained rock is rate-limited because of the difference in saturation relationships between rock types, retarding plume movement, as explained in Fig. 2.

showed that hysteresis in the constitutive relationship between capillary pressure and saturation can also retard or halt the advance of the plume through the reservoir, because the pressure in the non-wetting phase at the leading edge of the plume must be sufficiently large for counter-imbibition to occur readily in the tail region. The effect of this process was shown to be small relative to snap-off trapping under the conditions they explored.

(2) Capillary trapping can be caused by heterogeneity in the capillary entry pressure among reservoir rock types