Impacts of Relative Permeability on CO_2 Phase Behavior, Phase Distribution and Trapping Mechanisms

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Abstract

A critical aspect of geologic carbon storage, a carbon-emissions reduction method under extensive review and testing, is effective multiphase CO_2 flow and transport simulation. Relative permeability is a flow parameter particularly critical for accurate forecasting of multiphase behavior of CO_2 in the subsurface. The relative permeability relationship assumed and especially the irreducible saturation of the gas phase greatly impacts predicted CO_2 trapping mechanisms and long-term plume migration behavior.

A primary goal of this study was to evaluate the impact of relative permeability on efficacy of regional-scale CO_2 sequestration models. To accomplish this we built a 2-D vertical cross-section of a clastic geological storage reservoir site. This model simulated injection of CO_2 into a brine aquifer for 30 years. The well was then shut-in and the CO_2 plume behavior monitored for another 970 years. We evaluated five different relative permeability relationships to quantify their relative impacts on forecasted flow results of the model, with all other parameters maintained uniform and constant.

Results of this analysis suggest that CO_2 plume movement and behavior are significantly dependent on the specific relative permeability formulation assigned, including the assumed irreducible saturation values of CO_2 and brine. More specifically, different relative permeability relationships translate to significant differences in CO_2 plume behavior and corresponding trapping mechanisms.

Conceptual Model

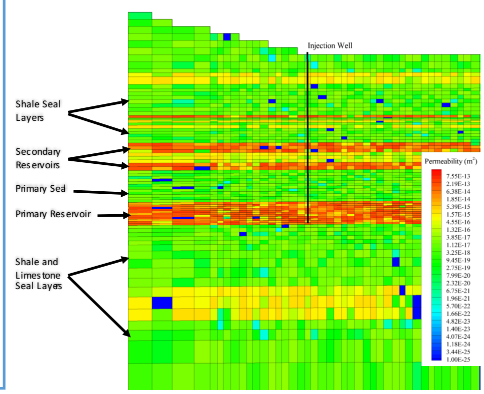
Study

Relative permeability function and parameter selection impact on numerical modeling of CCS.

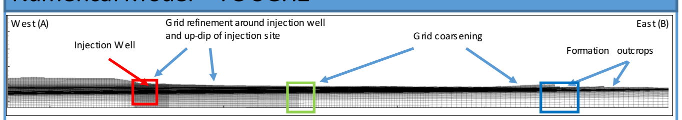
Model

A 2-D unconfined sloping reservoir based on a generic cross-section of a clastic geological storage site.

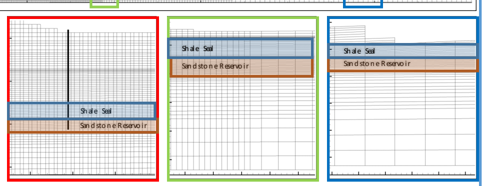
30 years injection of supercritical CO_2 into a heterogeneous sandstone saline aquifer



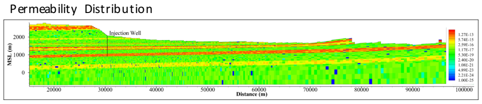
Numerical Model – TOUGH2



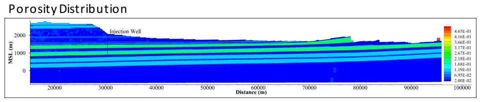
Initial Conditions	
Pressure	Hydrostatic
Temperature	25 + 10 °C/km
Salt Mass Fraction	0.036
CO_2 Mass Fraction	0.00001
Heat & Fluid	
Constant heat flux	0.06 W/m²
CO_2 Injection	1.0 Kg/s
Injection Time	30 years
Total Time	1000 years
Boundary Conditions	
Top Boundary	Fixed State
Pressure	101,360 Pa
East and West	Fixed State
Pressure	Hydrostatic
Bottom Boundary	No Flow



Permeability Distribution



Porosity Distribution

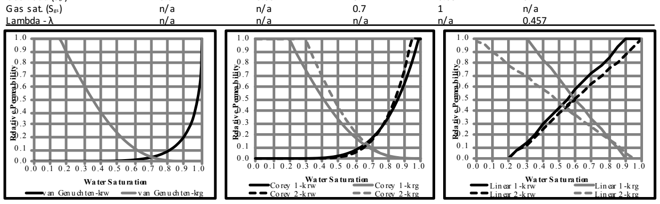


Relative Permeability Curves

Relative Permeability Functions	van Genuchten Function	Corey's Curve 1	Corey's Curve 2	Linear 1	Linear 2
Monitoring Periods	30 years Typical lifetime of coal power plant	80 years End of PISC monitoring period	140 years 60 years post monitoring	500 years Midpoint in simulation	1000 years End of simulation
Trapping Mechanisms	Residual Trapping	Solubility Trapping	Mobile CO_2		

Relative Permeability Parameters

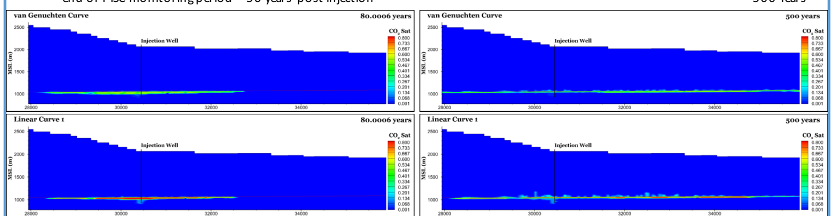
	Corey 1	Corey 2	Linear 1	Linear 2	van Genuchten
Water i-sat. (S_{lr})	0.2	0.3	0.2	0.2	0.15
Water sat. (S_{ls})	n/a	n/a	0.9	1	1
Gas i-sat. (S_{gr})	0.01	0.05	0.1	0.05	0.1
Gas sat. (S_{gs})	n/a	n/a	0.7	1	n/a
Lambda - λ	n/a	n/a	n/a	n/a	0.457



Relative Permeability Analysis

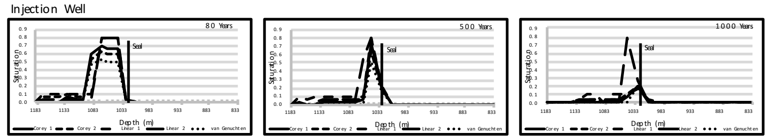
Supercritical CO_2 Saturation

end of PISC monitoring period – 50 years post injection — 500 Years

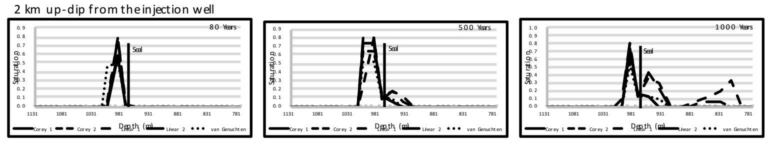


Monitoring Locations

Injection Well

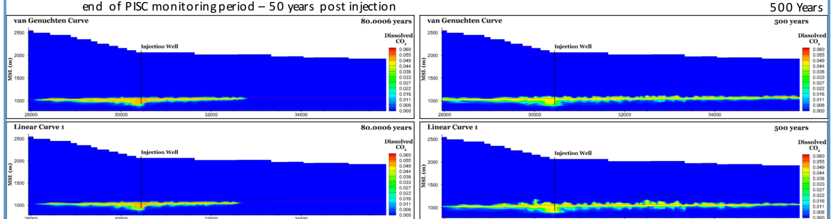


2 km up-dip from the injection well



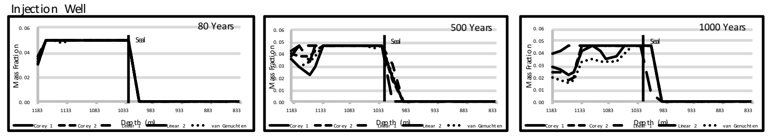
Mass Fraction of Dissolved CO_2

end of PISC monitoring period – 50 years post injection — 500 Years



Monitoring Locations

Injection Well



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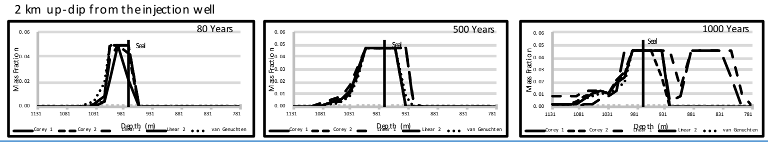
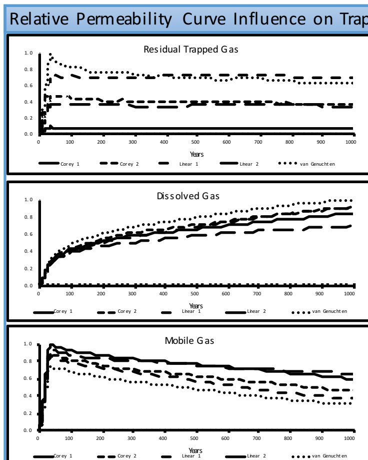


Relative Permeability Curve Influence on Trapping Mechanisms



CO_2 Mass Distribution by Relative Permeability Curve

	Monitoring Periods				
	30 years	80 years	140 years	500 years	1000 years
Residual CO_2	Increases with S_{gr}				
Corey1 (S_{lr} = 0.2, S_{gr}=0.01)	18,765	16,943	16,627	14,823	13,888
Corey2 (S_{lr} = 0.3, S_{gr}=0.05)	95,518	92,059	87,689	83,173	74,254
Linear1 (S_{lr} = 0.2, S_{gr}=0.1)	145,869	144,659	142,651	147,454	141,539
Linear2 (S_{lr} = 0.2, S_{gr}=0.05)	76,384	73,253	74,024	72,007	70,287
van Genuchten (S_{lr} = 0.15, S_{gr}=0.1)	203,101	170,573	159,943	138,950	130,594
Dissolved CO_2	Controlled by plume movement				
Corey1 (S_{lr} = 0.2, S_{gr}=0.01)	176,281	245,717	295,626	419,164	537,367
Corey2 (S_{lr} = 0.3, S_{gr}=0.05)	182,905	261,228	309,120	449,044	582,070
Linear1 (S_{lr} = 0.2, S_{gr}=0.1)	162,000	233,267	284,190	438,986	575,358
Linear2 (S_{lr} = 0.2, S_{gr}=0.05)	161,626	232,440	270,253	366,164	444,340
van Genuchten (S_{lr} = 0.15, S_{gr}=0.1)	201,487	282,536	345,437	504,140	631,674
Free CO_2	Inverse relationship with S_{gr}				
Corey1 (S_{lr} = 0.2, S_{gr}=0.01)	794,344	750,517	715,627	608,516	475,392
Corey2 (S_{lr} = 0.3, S_{gr}=0.05)	710,716	659,055	629,971	505,243	360,476
Linear1 (S_{lr} = 0.2, S_{gr}=0.1)	634,715	634,715	600,770	452,410	298,166
Linear2 (S_{lr} = 0.2, S_{gr}=0.05)	748,755	705,273	677,469	603,909	522,663
van Genuchten (S_{lr} = 0.15, S_{gr}=0.1)	582,464	556,973	517,358	383,919	242,036

Acknowledgement

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THE UNIVERSITY OF UTAH
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