

CO₂ Geological Storage Capacities: Consideration of Critical Parameters of Static and Dynamic Processes

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Summary

Geological storage of anthropogenic CO₂ is one of the most viable ways to reduce carbon emissions into the atmosphere and to aid in meeting the goal of net-zero carbon emissions. Geological storage of carbon dioxide occurs through various mechanisms and processes: in a critical gas state as a mobile or trapped immobile gas phase in pore space, as a dissolved gas in residual oil and water of depleted hydrocarbon reservoirs or deep saline aquifers, as an adsorbed gas in organic rich rocks and coals, and in the form of carbonate solids precipitated out of water or through chemical interactions with reservoir rocks. The long-term storage capacity of CO₂ and relative importance of every component for a geological site depends on the spatial distribution of available pore volume, fluid saturations, PVT properties of each fluid, solubility of CO₂ in liquid phases, and the chemistry of formation water and the mineralogy of the porous rocks under equilibrated in situ pressure and temperature. However, the long-term “equilibrated” static state is driven by multiple dynamic processes controlled by various parameters, such as injection operations (injection rate or injection pressure and initial reservoir pressure), multiphase flow processes or phenomena (permeability, relative permeability, capillary pressure), convection and/or diffusion of CO₂ in water (diffusivity, water density), and hydrodynamic boundaries of the storage sites (closed or open with pressure support). All the parameters of the static and dynamic processes ultimately determine the short- and long-term CO₂ storage capacity. So far, the relative importance of all abovementioned parameters and associated process are poorly understood. In this study, the controlling effects of the most important parameters for CO₂ in saline aquifers are investigated through examples of potential CO₂-storage deep aquifers or reservoirs from the Western Canada Sedimentary Basin.

Method & Workflow

Key components or mechanisms of CO₂ geological storage are critically reviewed. Literature of measured solubility of CO₂ and mixture with impurities in water of different salinities under typical ranges of pressure and temperature are reviewed and compiled. The compiled solubility data is used to validate and fine-tune the Peng-Robinson EOS PVT model of Phreeqc for better CO₂ physical properties and solubility prediction. Using examples of potential CO₂ storage sites from the Western Canada Sedimentary Basin, the contributions of mobile phase, solution gas in water and precipitation/dissolution of carbonates to total carbon storage under variable conditions (saturation, salinity, pressure, and temperature) are investigated using the validated PVT and Phreeqc models.

Using the validated models, the transport phenomena of hydrodynamic pressure-driven fluid flow, CO₂ diffusion in water and density-driven convection are analyzed. The static model results of solubility of CO₂ in water and water-vapor solubility in CO₂, PVT properties of CO₂ and water are used in a numerical two-phase flow model to further investigate the controls of injection operations, relative permeability and permeability, pore volume compressibility, hydrodynamic boundary conditions (closed or pressure-supported) of the storage site in relation

to the short-term and long-term CO₂ storage potential and the contributing importance of each mechanism or factor.

Results, Observations, Conclusions

Static modeling results suggest that CO₂ solubility in brine and H₂O-vapor in a CO₂-dominant phase can be predicted to match literature data with an average absolute relative deviation (AARD) less than several percent for most data sets (e.g., Figure 1). Temperature, pressure and salinity and aqueous geochemistry of the water all have significant effects on the solubility, with pressure having the strongest effect. Dynamic modeling results suggest that the ultimate or long-term storage of CO₂ at a specific site or saline aquifer are controlled by many factors. Under typical pressure and temperature conditions for saline aquifers, CO₂ in a critical state phase has the highest storage capacity per unit volume, and significantly less CO₂ dissolved and stored in saline water. The relative volumes of critical CO₂ and CO₂-saturated water are controlled by boundary conditions of the storage site, permeability and relative permeability (end points), heterogeneities of the reservoir, pore compressibility, and injection operations, listed in an approximate order of decreasing importance.

This study demonstrates a simple and comprehensive workflow to quantify the contributions of different mechanisms to short- and long-term CO₂ storage capacity and proposes a systematic way to understand the controlling effects of various parameters critical to static and dynamic processes governing short- and long-term CO₂ geological storage potential. Overall, the approach and the results provide a useful guide for CO₂ storage site study and capacity assessment.

Acknowledgements

References

Liu, Y., M. Hou, G. Yang, B. Han, 2011, R Solubility of CO₂ in aqueous solutions of NaCl, KCl, CaCl₂ and their mixed salts at different temperatures and pressures, J. of Supercritical Fluids vol. 56, 125–129.

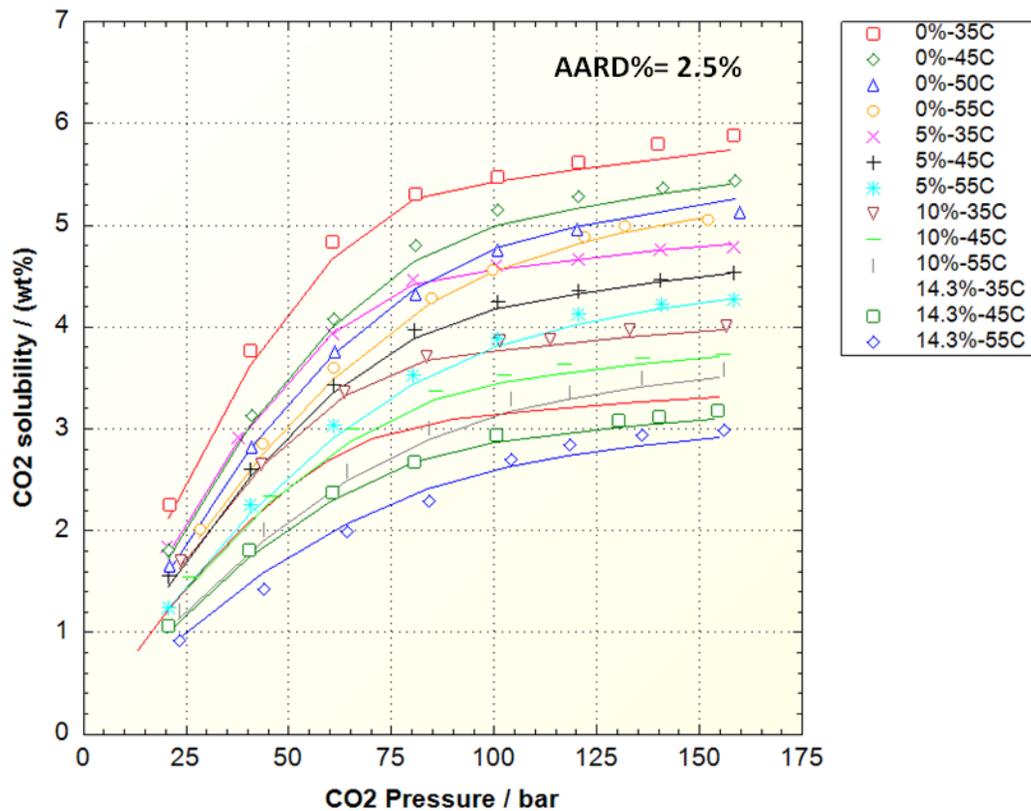


Figure 1. Solubility of CO₂ in aqueous solution of NaCl+KCl+CaCl₂ at temperatures from 33 °C to 55 °C and different salinities (0 – 14.3%) with a weight ratio of NaCl:KCl:CaCl₂ = 1:1:1. The solid lines represent the modeled solubility of this study and symbols represent the experimental solubility from the study by Liu et al. (2011).