Short or Long Timescales for Dissolution Trapping in CO\textsubscript{2} Storage?

Rory Leslie\textsuperscript{a}, Andrew J. Cavanagh\textsuperscript{a}, R. Stuart Haszeldine\textsuperscript{a,b}, Gareth Johnson\textsuperscript{c}, Anna Pontén\textsuperscript{d}, Philip S. Ringrose\textsuperscript{d,e} and Stuart M. V. Gilfillan\textsuperscript{a}

\textsuperscript{a}School of GeoSciences, Grant Institute, University of Edinburgh, Edinburgh EH9 3FE, UK
\textsuperscript{b}SCCS, High School Yards, Infirmary Street, Edinburgh EH1 1LZ, UK
\textsuperscript{c}Department of Civil and Environmental Engineering, University of Strathclyde, Glasgow G1 1XZ, UK
\textsuperscript{d}Equinor ASA, 7053 Trondheim, Norway
\textsuperscript{e}Department of Geoscience and Petroleum, Norwegian University of Science and Technology, 7012 Trondheim, Norway

Abstract

The dissolution of injected CO\textsubscript{2} into formation water is a chemical trapping process that can remove millions of metric tonnes of mobile CO\textsubscript{2} from storage reservoirs (Leslie et al., 2021). Naturally occurring CO\textsubscript{2} reservoirs are valuable analogues that can help to predict the long-term performance of anthropogenic CO\textsubscript{2} storage (Gilfillan et al., 2008). The noble gas and $\delta^{13}$C content within CO\textsubscript{2} can be used to quantify the fraction of gaseous CO\textsubscript{2} removed by dissolution (Gilfillan et al., 2009). These findings provide valuable benchmarking for predictive models of geochemical trapping and storage security in anthropogenic CO\textsubscript{2} reservoirs. This is of interest to CO\textsubscript{2} storage operators and regulators.

We test two conceptual end-member models for CO\textsubscript{2} dissolution in reservoirs. In model (a) CO\textsubscript{2} dissolution during the injection and migration phase is most significant. The early dissolution rate is high, due to the large volumes of CO\textsubscript{2}-free formation water that the migrating CO\textsubscript{2} plume contacts and displaces. After the plume has become structurally or stratigraphically trapped, CO\textsubscript{2} dissolution rate decays rapidly and equilibrium is reached as the adjacent formation water becomes CO\textsubscript{2} saturated. In model (b) the dissolution rate is still highest during injection and migration of the CO\textsubscript{2}, but the rate declines less rapidly after stabilisation of the plume. Dissolution rate is maintained by the processes of diffusion and density-driven aquifer convection. These processes supply the trapped CO\textsubscript{2} plume with formation water that is undersaturated in CO\textsubscript{2}. This supply of undersaturated formation water allows the dissolution of gaseous CO\textsubscript{2} to persist over geological timescales and causes a greater fraction of the CO\textsubscript{2} to dissolve.

We present new results on the long-term fate of CO\textsubscript{2} from the Sheep Mountain and McElmo Dome CO\textsubscript{2} fields in Colorado, USA. At Sheep Mountain, CO\textsubscript{2} is trapped in a thrusted anticline structure (Roth, 1983). The reservoir comprises of a Mesozoic-age paralic to shallow marine sandstone reservoir (Young, 1960). McElmo Dome is a Mississippian-age carbonate reservoir, where CO\textsubscript{2} is trapped in an anticline structure (Gerling, 1983). Both fields have similar characteristics to reservoirs being considered for saline aquifer CO\textsubscript{2} storage in the UK, Europe and North America.

Using analyses of CO\textsubscript{2} gas samples from commercial boreholes we calculate the fraction and mass of CO\textsubscript{2} that has been geochemically trapped by dissolution at Sheep Mountain and McElmo Dome. This calculation is based on the difference between CO\textsubscript{2} and the conservative trace gas He\textsuperscript{3}. In both reservoirs, dissolution trapping is responsible for
millions of metric tonnes of gaseous CO$_2$ removal.

The Sheep Mountain and McElmo Dome CO$_2$ source is attributed to Cenozoic age magmatism (Gilfillan et al., 2008; Penn and Lindsey, 2009). Using the age dates of these rocks to constrain the timing of CO$_2$ charge, the average CO$_2$ dissolution rate over storage time is calculated. Bravo Dome in New Mexico, USA is the only analogue field where CO$_2$ dissolution rate has previously been quantified (Sathaye et al., 2014; Zwahlen et al., 2017). Our results from Sheep Mountain and McElmo Dome expand this valuable analogue database. The average dissolution rates from the analogue fields are compared to rates from operating CO$_2$ storage reservoirs and numerical modelling studies.

We create analytical models to estimate the mass of CO$_2$ trapped by dissolution during migration. These are compared to the estimates of total dissolved mass calculated from the CO$_2$/$^3$He ratio. The difference in these values is used to estimate the contribution that post-emplacement diffusion and convection make to total dissolution. Mapping the variation in dissolution percentage across the reservoirs, we show that proximity to the gas-water contact has no influence on the fraction of CO$_2$ dissolved. Our findings support a model where most dissolution trapping occurs during migration of the CO$_2$ plume. Dissolution after the establishment of a stable gas-water contact is less significant. Therefore, in an anthropogenic storage reservoir, significant percentages of injected CO$_2$ can be geochemically trapped through dissolution within monitoring timescales.

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References


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