Natural Mitigation of CO2 Leakage Accumulations

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The role of overlying aquifer in the natural remediation of CO_2 vertical migration

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Abstract

Carbon dioxide geological storage in deep saline aquifer is considered as a promising solution to ensure the necessary decrease of CO_2 anthropogenic emissions. Its industrial development is above all conditioned by its safety demonstration. Several modes of trapping take part in the confinement of the injected CO_2 within saline aquifers: structural and residual trapping (as a gas phase), solubility trapping (dissolved in the aqueous phase) and mineral trapping. Despite these trapping modes occurring in the storage aquifer, potential gas leakage into an overlying aquifer is a risk scenario that should be considered. As for every risk scenario, safety barriers should be set-up in the aim of preventing, controlling or limiting the consequences of the considered risk event. This study aims at investigating the role played by the overlying aquifer formation as a safety barrier in case of CO_2 accumulation by focusing on its “buffering capacity”, which we define as the natural capacity of the overlying aquifer containing mobile gas (secondary accumulation) to prevent any additional leakage and further upward migration.

In this work, we study the conditions for an efficient natural buffering capacity, i.e. the conditions at which the natural flow processes could lead to the immobilization of the buoyant mobile gas that would have leaked out. The immobilization is allowed through similar processes than in the storing aquifer (i.e. through solubility and residual trapping notably). The natural buffering efficiency is mostly assessed through the time period needed to immobilize the CO_2 secondary accumulation, hence preventing the risks of additional migration: the acceptable time frame is defined compared to the one needed for alternative active remediation methods (such as extraction of the CO_2 accumulation through pumping in the overlying aquifer, or water injection). Note that, aquifer disruption due to engineered methods (e.g. hydrodynamic perturbations induced by active solutions) as well as the extra expenditures associated with these measures are additional important criteria to consider and are discussed in our study.

The natural buffering capacity of an overlying aquifer is highly site-specific. Groundwater flow, aquifer tilt, aquifer parameters for relative permeability and capillary pressure, leakage properties are, in this view, essential parameters. In our study, the ranges of variation of these parameters are assumed based on representative properties for aquifer formations (considering both silicastic and carbonate rock formations). Similarly, the scenarios for leakage rates are in the order of magnitude of the values found in literature both regarding leakage modelling and field analogues values. The flow processes are accounted for using the numerical tool TOUGH2 integrating history dependant effects (hysteresis) associated with capillary trapping. The base scenario consists of a gas leakage within an overlying aquifer through a less permeable zone in the caprock (faulted zone for instance). According to the different properties considered for the formation and to the characteristics of the leakage (duration, rate), the ratio between the advective effects (due to the leakage and to the groundwater natural pressure gradient), the capillary effects and the gravity ones is modified implying changes in the evolution of the mobile gas quantity. Considering a leakage of about a few thousands of tons during a year over a hundred meters long fault, the time required for the total trapping of the CO_2 secondary accumulation varies from a few months to a couple of years depending on the cases modelled. On this basis, we demonstrate that an aquifer with low vertical permeability and with a high groundwater flow (or tilted) is residual and dissolution friendly; conversely, a no-flow aquifer with anticline will not be favourable to dissolution and residual trapping. Moreover, our study shows how the mobility ratio between the liquid and gas phase,

which is governed by the relative permeability laws for given fluid properties (viscosity and density), is essential in the trapping of the gas phase. The capillary pressure strength, which varies significantly from one aquifer to another, may play a considerable role as well. By notably discussing quantitatively the importance of these effects, we are able to discriminate the cases where the overlying aquifer can naturally play the role of an efficient safety barrier and the parameters essential for this screening.

The results of this present study can support the decision-making process on a generic mitigation strategy in the case of CO_2 migration from the reservoir to an overlying aquifer. Our results show that a potential remediation option can rely on the natural processes underlying the buffering capacity of this aquifer. A parallel can be drawn with the “monitored natural attenuation” concept in the fields of pollution engineering and contaminants remediation relying on the combination of the natural processes acting for the reduction of the contaminant concentration, on monitoring of their effectiveness and on controlling the source of pollution. Rather than a default choice, this decision should be argued based on the conditions highlighted in this study that makes the attenuation acceptable. In some cases, the conditions might not be met to allow a satisfying immobilization of the leaking gas without human intervention. In these types of situations, alternative remediation options can rely on the active enhancement of the solubility and capillary trapping through some engineered measures (e.g. through brine injection or fluid extraction for instance).