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Review of CO_2 storage efficiency in deep saline aquifers

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ABSTRACT

At the time the IPCC Special Report on Carbon Capture and Storage was published in 2005, the concept of CO_2 storage efficiency was not introduced yet and, consequently, no numerical values were published in the literature. CO_2 storage efficiency is defined as the ratio of the volume of CO_2 injected into an aquifer rock volume to the pore space in that volume and this concept has been first introduced in 2007 in regional-scale assessments of storage capacity in the United States and Europe. Since then many papers, reviewed in this article, have been published on the subject of efficiency of CO_2 storage and associated values. CO_2 storage efficiency depends on a multitude of factors that can be grouped into several categories: (1) Characteristics of the storage aquifer, such as in situ conditions of pressure, temperature and salinity, displacement characteristics of the CO_2/brine system, lithology, porosity, permeability, heterogeneity and anisotropy, aquifer areal extent, thickness and boundaries; (2) Characteristics of the confining aquitards, mainly permeability and capillary entry pressure; (3) Characteristics of the CO_2 storage operation, such as injection rate, duration of injection; number of injection wells, their orientation and their spacing, and injection strategy, including water production and/or injection; and (4) Regulatory constraints, such as maximum bottom-hole injection pressure, and definitions used to establish the volume of rock assigned for CO_2 storage for a given project, such as scale of assessment (local or regional), relevant time (e.g., at cessation of injection or at plume immobilization), and relevant aquifer area (e.g., footprint of the CO_2 plume itself, area where aquifer pressure is higher than a critical pressure, or area of tenure). Depending on the combination of factors listed above, values of storage efficiency as calculated to date and published in the literature vary in a wide range (from <1% to >10%, by a factor of 20 and even higher) and no single value or set of values can be universally used. Storage efficiency has both a spatial and a temporal dependency; being first pressure- and then space-limited; therefore it is critical in all assessments to specify the relevant aquifer area and time of reference. For closed aquifers, the cross-over time from pressure-limited to space-limited is achieved very quickly, and storage efficiency is based on the compressibility of the system. For open aquifers, a CO_2 storage operation is most likely pressure-limited during its entire life. Storage resource estimates are theoretically time and space independent in the sense that the entire aquifer is considered, and the estimate represents what would be achieved if all the aquifer pore space would be accessible through a very large number of wells and over a very long period of time, much longer than a project life-time and the period of time needed to achieve climate stabilization. Volumetric estimates could be used for regional-scale evaluations of CO_2 storage resources using values at the lower end of the spectrum of published values for storage efficiency. Dynamic estimates, based on numerical simulations that take into account operational and regulatory factors should be used for local-scale CO_2 storage reserves estimates. Storage efficiency can be increased using storage engineering technology, such as water extraction and/or (re)injection, and the type and location of various injection and producing wells.

1. Introduction

Interpretation of the temperature record on a scale of centuries to millennia indicates an unequivocal warming of the climate system, with unprecedented changes since 1950 (IPCC, 2013). This warming, noticeable since the beginning of the industrial revolution in 1750, is most likely due to an increase in atmospheric concentrations of greenhouse gases (GHG) as a result of human activity, such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Land use (agriculture and deforestation) is the major factor in the increase in CH_4 and N_2O concentrations, and the use of fossil fuels for power generation, industrial processes and

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