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CO_2 migration in the vadose zone: experimental and numerical modelling of controlled gas injection

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The mobility of CO_2 in the vadose zone and its subsequent transfer to the atmosphere is a matter of concern in the risk assessment of the geological storage of CO_2. In this study the experimental and modelling results of controlled CO_2 injection are reported to better understanding of the physical processes affecting CO_2 and transport in the vadose zone. CO_2 was injected through 16 micro-injectors during 49 days of experiments in a 35 m3 experimental unit filled with sandy material, in the PISCO$_2$ facilities at the ES.CO$_2$ centre in Ponferrada (North Spain). Surface CO_2 flux were monitored and mapped periodically to assess the evolution of CO_2 migration through the soil and to the atmosphere. Numerical simulations were run to reproduce the experimental results, using TOUGH2 code with EOS7CA research module considering two phases (gas and liquid) and three components (H_2O, CO_2, air). Five numerical models were developed following step by step the injection procedure done at PISCO$_2$. The reference case (Model A) simulates the injection into a homogeneous soil(homogeneous distribution of permeability and porosity in the near-surface area, 0.8 to 0.3 m deep from the atmosphere). In another model (Model B), four additional soil layers with four specific permeabilities and porosities were included to predict the effect of differential compaction on soil. To account for the effect of higher soil temperature, an isothermal simulation called Model C was also performed. Finally, the assessment of the rainfall effects (soil water saturation) on CO_2 emission on surface was performed in models called Model D and E.

The combined experimental and modelling approach shows that CO_2 leakage in the vadose zone quickly comes out through preferential migration pathways and spots with the ranges of fluxes in the ground/surface interface from 2.5 to 600 g·m-2·day-1. This gas channelling is mainly related to soil compaction and climatic perturbation. This has significant implications to design adapted detection and monitoring strategies of early leakage in commercial CO_2 storage. The presence of soils with different compactions at surface influences the CO_2 dispersion. The inclusion of soils with different permeability, porosity and liquid saturation results in preferential pathways. The formation of preferential pathways in the soil and hot spots on the surface has commonly been observed in natural systems where deep CO_2 fluxes interact with shallow aquifers. Increase of ambient temperature increases CO_2 fluxes intensity whereas rainfall decreases CO_2 emission in gas phase and trap it as aqueous species in the porous media of the soil.

A good accuracy has been obtained for surface CO_2 fluxes location and intensity between experimental and modelling results taking into account the selected equation of state, the soil characteristics and the operational conditions. Phenomena of compaction and preferential pathways located only in the first centimetres of the soil can explain the heterogeneity of CO_2 fluxes in the 16 m2 surface area of PISCO$_2$ experimental platform.