Impact of CO_2 Permeation on Inter-layers and Reservoir Cap-rock Sealing Efficiency

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GeoNetZero — Geoscience Solutions to address the Net Zero Challenge

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Why do we need CO_2 to be captured and stored in geological formations?

CO_2 release is a key mechanism affecting the stability of the Earth's climate by capturing the heat in the atmosphere (Surampalli et al., 2015). Therefore, CO_2 geological storage is considered a long-term solution for limiting the temperature increase by reducing the CO_2 emissions during the transition period to sustainable clean energy (Al-Khoury et al., 2014). Additionally, Several potential locations can be used for CO_2 geological storage such depleted as oil and gas reservoirs where it is not limited by the new development of technology. Furthermore, this mitigation is associated with risks of leakage as shown in Figure 1.

Geological Storage Options for CO2

1. Unmineable Coal Beds
2. Depleted oil and gas reservoirs
3. Deep Saline Aquifers
4. Salt Cavens

CO2 Potential Leakage Pathway

A. Active Fault
B. Active Fracture
C. Abandoned Well
D. Capillary pressure
E. Diffusion loss

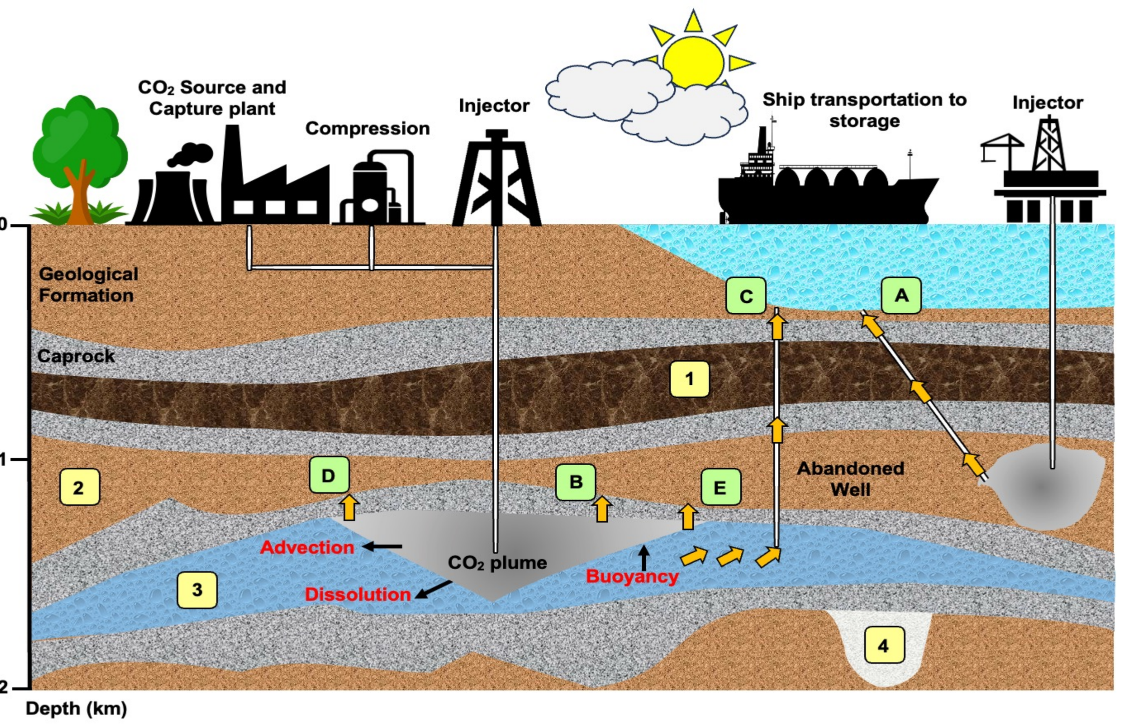

Figure 1: Schematic diagram showing potential geological carbon storage sites and potential leakage pathways (RIGBY, S. P. & ALSAYAH, A. 2024).

Research Aims and Objectives

Understanding and predicting the unusual migration of CO_2 plumes by evaluating their behaviour in depleted compartmentalised reservoirs with thin shale interlayers (Sleipner-like field). Further, investigating the physical, mechanical, and chemical transportation of CO_2 in the storage. This was investigated using a 3D field-scale reactive transport model built using comprehensive coupling processes (trio of fully coupled hydrogeological, geochemical, and geo-mechanical) as shown in Figure 2.

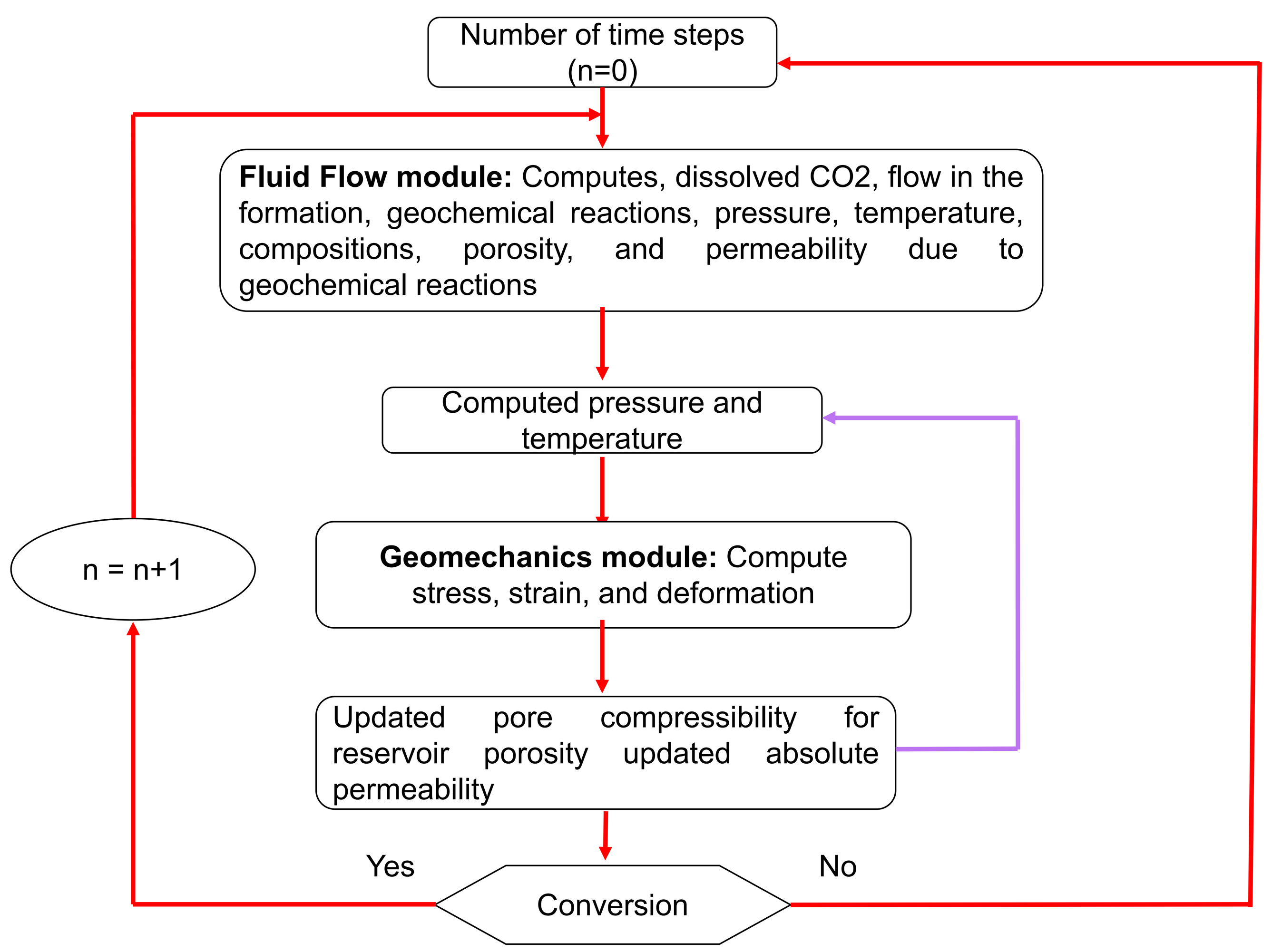

Figure 2: Coupling processes involved in the simulation.

Numerical Scenarios

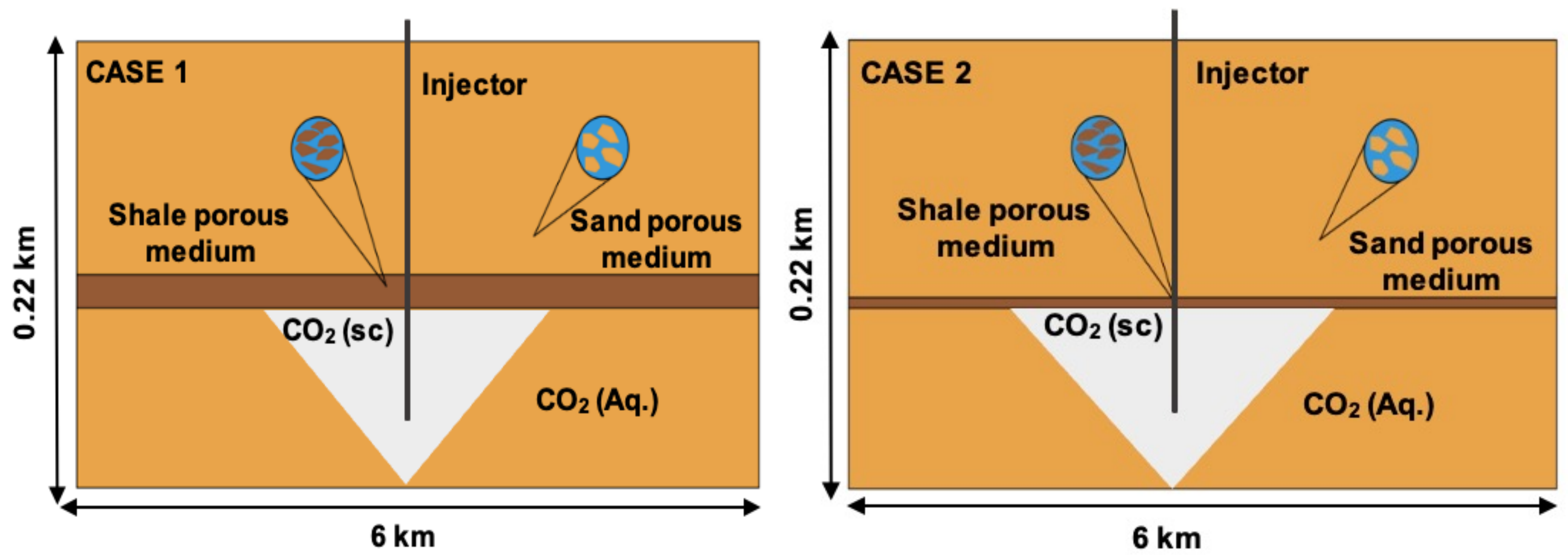

Figure 3: Case 1 represents a single 3 m interlayer and Case 2 shows a single 0.3 m interlayer. in IK cross-sectional view. Light and dark brown represent Utsira Sandstone and Nordland shale, respectively.

Results and Discussion

Counter-intuitively, a more effective local seal is provided by a thinner (0.3 m) shale inter-layer compared to a thicker (3 m) shale inter-layer. Unexpected leakage arose in Case 1 compared to Case 2 where 20% of CO_2 (Aq.) managed to escape to the overburden.

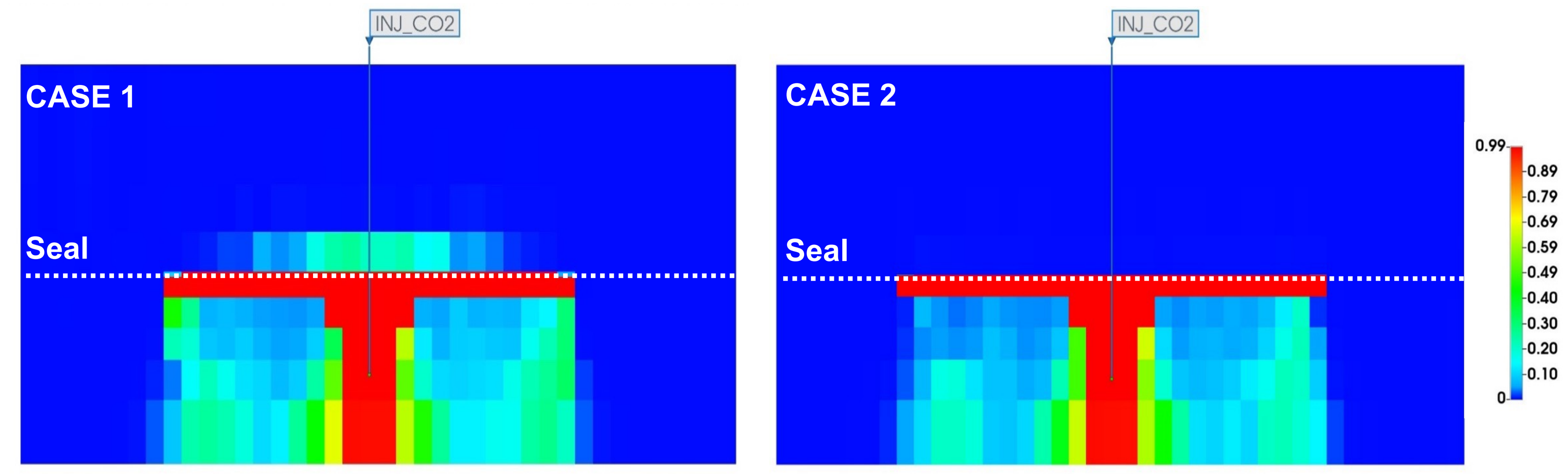

Figure 4: IK cross-sectional view of CO_2 plume migration behaviour after 100 years of injection, the scale shows CO_2 global mole fraction.

This unexpected effect arose due to a greater increase in vertical displacement in Case 1 compared to Case 2. Further, a higher capillary pressure breakthrough in Case 1 compared to Case 2 thus meant more $scCO_2$ (18%) was allowed into the thick interlayer (Case 1).

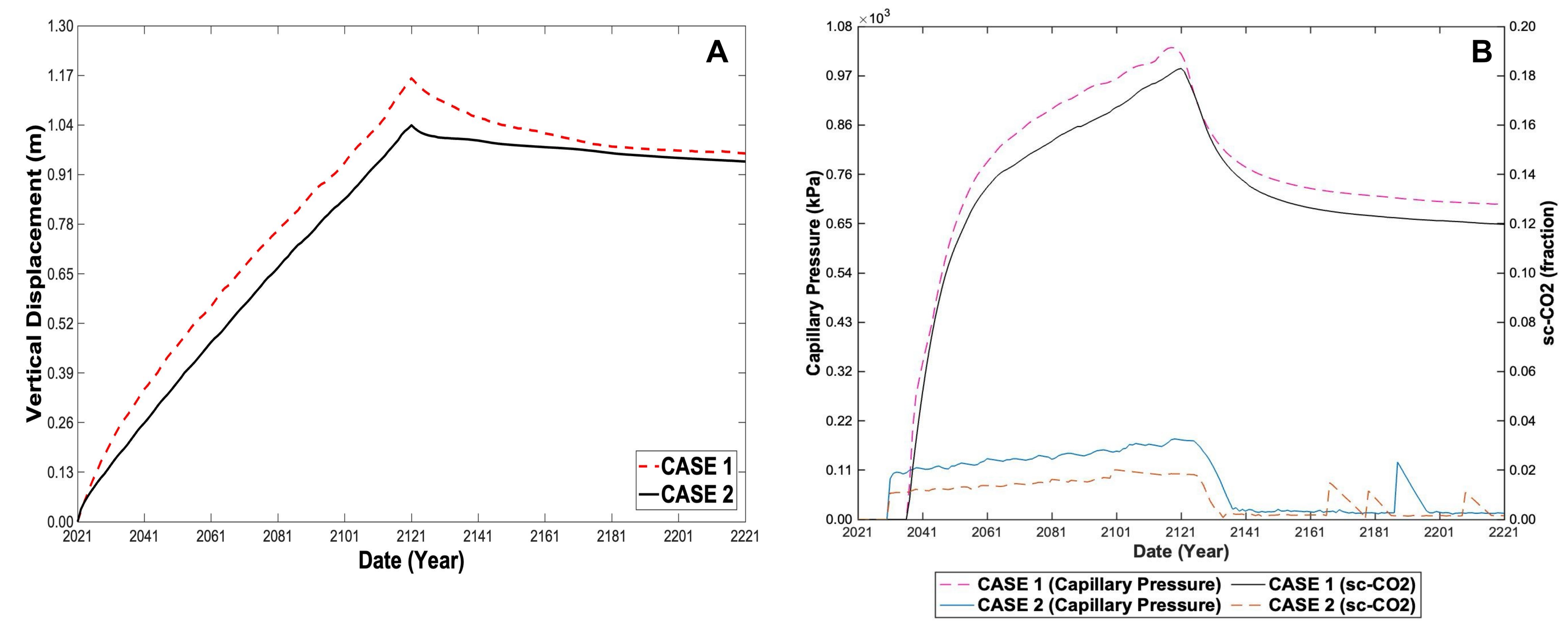

Figure 5: Vertical displacement change of the shale inter-layer for Cases 1 and 2 (A), and Water-Gas capillary breakthrough pressure behaviour of shale inter-layer for Cases 1 and 2 (B)

Extensive chemical reactions within the thicker inter-layers occurred, including changes in pH, larger solubility of CO_2 and a decrease in brine salinity. Faster calcite reactions, along with other minerals, occurred within the thicker inter-layer (Case 1) compared to Case 2. There was an enhanced level of dissolved CO_2 at the reservoir/inter-layer boundary. Thus, an increased concentration gradient, in turn, caused increased diffusive loss in Case 1.

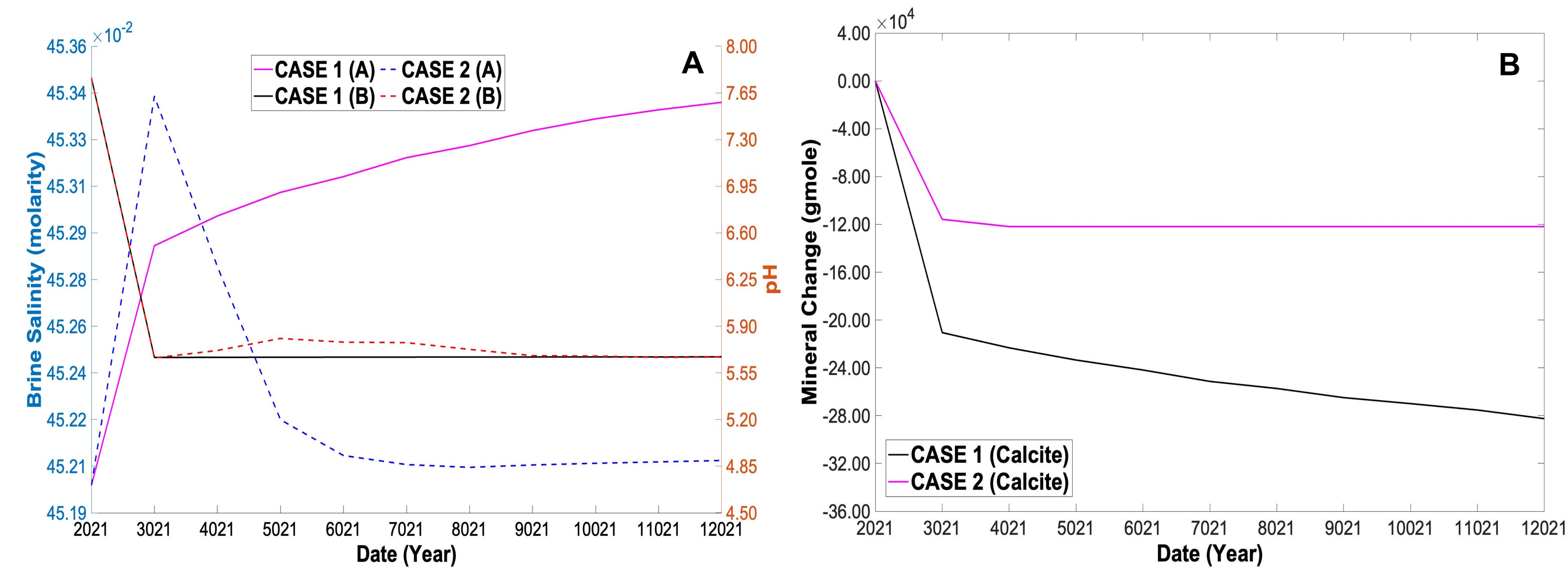

Figure 6: Variation in brine pH and brine salinity (A), and variation in mineral content within the shale inter-layers for Cases 1 and 2 (B).

Once the $scCO_2$ injection stopped, the dissolved CO2 rate rapidly increased in both Cases. More CO_2 was trapped by hysteresis in Case 2 by 8.6% more compared to Case 1. The amount of CO_2 trapped in minerals was low during the initial 10,000 years.

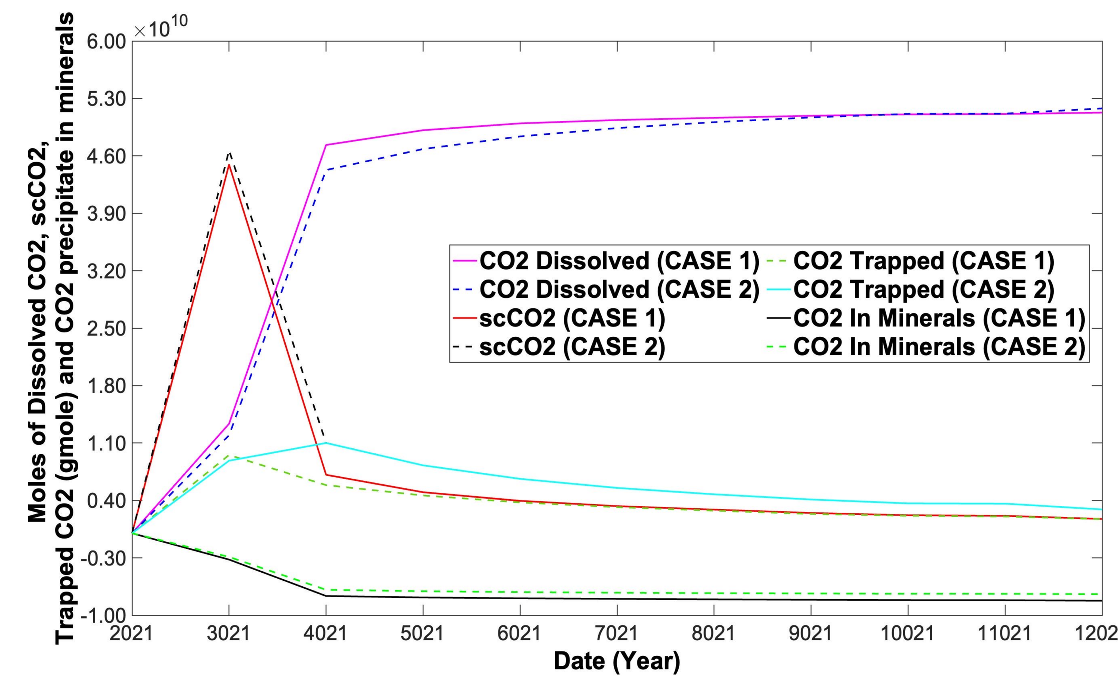

Figure 7: Variation over time of the number of moles of CO_2 present in various states, including dissolved into native brine, as $scCO_2$, as CO_2 (aq.), as CO_2 precipitated in minerals, and as CO_2 trapped at field scale for Cases 1 and 2.

Summary of the unexpected leakage

Expansion of Interlayer and nearby reservoir pore volume due to geo-mechanical effect was larger in Case 1 than in 2. Thus, a large accumulation of CO_2 below the interlayer resulted in higher capillary breakthrough pressure in Case 1 than in 2, causing, more scCO2 to enter the thick interlayer (Case 1). Further, more extensive chemical reactions occurred in the thick Interlayer, which led to the enhancement of the dissolved CO_2 level at the reservoir/interlayer boundary and, in turn, increased the diffusive loss via the thick interlayer towards the overburden.

Conclusions

- In this case, a thinner shale inter-layer is more efficient compared to a thicker shale inter-layer in terms of preventing the CO_2 vertical migration.
- The largest Breakthrough capillary pressure exhibited in Case 1 resulted in 18% of scCO2 escaping from the reservoir into the inter-layer, plus 20% of CO2 (Aq.) in Case 1 managed to escape towards the overburden by diffusion.
- Sensitivity analysis was carried out on grid-block size (from 8000 to 50,000), and relative permeability and capillary pressure and similar results were obtained.

Reference