Introduction

Anticlines are often preferred for carbon sequestration due to their ability to provide a secure containment, similar to oil and gas traps. However, the availability and storage capacity of anticlines can be limited, prompting the exploration of alternative options, such as open aquifers or unconfined reservoirs, which rely on residual trapping and dissolution to sequester injected CO_2. This paper aims to demonstrate that injecting CO2 into the flanks of an anticlinal structure can enhance the overall CO_2 sequestration capacity by leveraging the trapping mechanisms of open aquifers, specifically residual trapping and dissolution.

A case study comparing two injection strategies is presented. The first scenario involves injecting CO_2 into the structural closure, where it remains primarily in a mobile phase, with a limited storage capacity of 400 million tons (Mtons). In contrast, the second scenario involves placing injectors on the flanks of the structure, at the lowest possible point within the fetch area, allowing the CO_2 plumes to migrate upward and eventually become trapped in the structural closure. Notably, this approach doubles the storage capacity, highlighting the potential benefits of flank injection in optimizing CO_2 sequestration.

Numerical Simulation

A static model was created to represent the entire anticlinal structure. The target reservoir is characterized by homogeneous properties, with a porosity of 25% and a permeability of 200 millidarcies (md). Two distinct scenarios were simulated: the first scenario involves the placement of 4 injection wells near the crest of the structure, while the second scenario features 8 injector wells positioned on the flanks of the structure. In both scenarios, CO_2 injection occurs over a period of 100 years, with each well injecting 1 million tons per year. The total amount of CO_2 injected differs between the two scenarios, with 400 million tons (Mtons) injected in the crestal scenario and 800 Mtons injected in the flank scenario.

a) b)

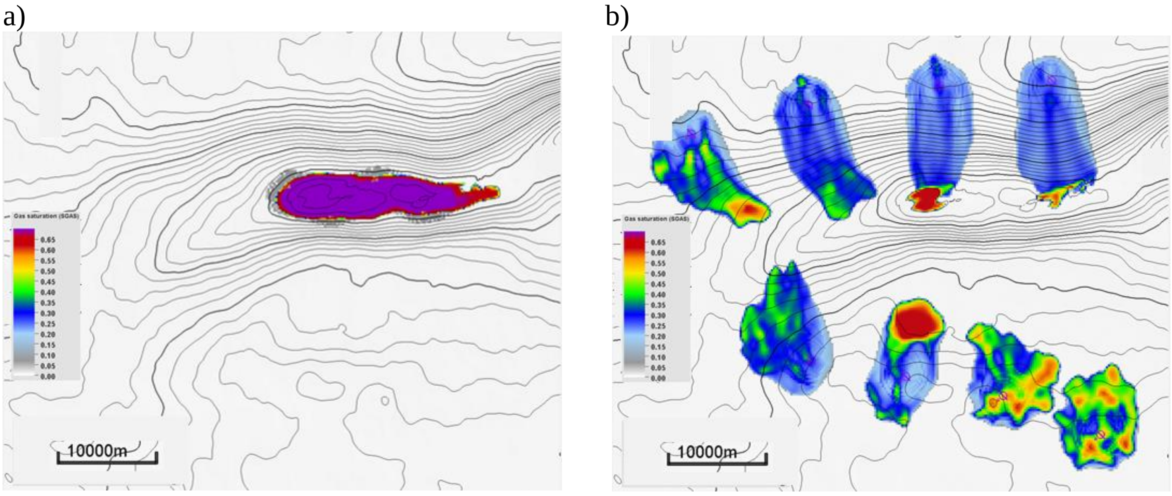

Figure 1 *Contour map of a hypothetical low relief anticlinal structure and CO_2 saturation. a) crestal injection scenario and b) flank injection scenario after 1000 years of injection.*

Following the injection phase, the simulation is extended for an additional 1,000 years to allow for the upward migration of CO_2. After this period, the crestal injection scenario shows minimal changes, with the CO_2 remaining largely confined to the structural trap (Figure 1a). The limitation of injecting CO_2 into the crestal part of the structure becomes apparent, as sequestration is restricted to the pore volume of the trap, resulting in minimal residual trapping and dissolution. The majority of the CO_2 remains in a mobile state, with saturations exceeding 80%. Dissolution occurs at a very slow rate, as the CO_2-water contact area is static and limited in extent.

In contrast, the flank injection scenario exhibits significant changes after 1,000 years (Figure 1b). The CO_2 plumes have migrated upward at varying rates, depending on the reservoir's inclination. Plumes on the steeper flanks advance more rapidly, with two of them reaching the structural trap. The leading edges of these plumes exhibit high CO_2 saturations, which gradually decrease towards the trailing edges. In areas with gentler slopes, the plumes propagate much more slowly, resulting in patchy and uneven saturation distributions. This highlights the differences in migration behavior and trapping efficiency between the crestal and flank injection scenarios.

Comparison of mobile, trapped and dissolved CO2

After 100 years of injection, the eight-well scenario exhibits twice the amount of mobile, trapped, and dissolved CO_2 as the four-well scenario. During the injection period, both scenarios experience a rapid increase in trapping and dissolution, as CO_2 quickly interacts with the surrounding reservoir and aquifer. However, following the cessation of injection, the two scenarios diverge. In the eight-well flank injection scenario, the mobile phase declines rapidly, while trapping and dissolution continue to increase, albeit at a slower rate. In contrast, the crestal four-well scenario exhibits a drastically different behavior. After injection stops, the mobile phase decreases only marginally, trapped CO_2 remains constant or decreases, and dissolved CO_2 increases at a very slow pace.

The key difference between the two scenarios lies in the limitations imposed by injecting CO_2 into the crestal part of the structure. This approach restricts CO_2 sequestration to the pore volume of the structural trap, where the majority of CO_2 remains in a mobile state. As a result, the amount of CO_2 that can be trapped is limited to the pore volume of the structural trap, which in this case is capped at 400 Mton. In contrast, the eight-well flank injection scenario, which can sequester up to 800 Mton, demonstrates that injecting CO_2 into the flanks of the structure allows for the utilization of additional sequestration mechanisms, such as residual trapping and dissolution. These mechanisms actively eliminate mobile CO_2, highlighting the potential for enhanced CO_2 sequestration through flank injection.

Conclusions

The crestal injection method captures the majority of CO_2 in a mobile state, relying on the structural trap's seal for containment. In contrast, injecting CO_2 into the flanks of the structure enables it to gradually migrate upwards to a structural or stratigraphic closure. This approach offers several advantages, including increased contact between CO_2 and the aquifer, which enhances dissolution and allows access to additional pore volume, promoting residual trapping. Furthermore, flank injection can be distributed over a larger area, reducing the risk of pressure buildup in the aquifer. As a result, the total volume of CO_2 sequestered through flank injection can significantly exceed the capacity of the structural trap alone.

References

Ringrose, P. How to Store CO_2 Underground: Insights from early-mover CCS Projects. 1st ed. 2020.