Baffled confinement systems: Characterizing, de-risking and permitting unconventional seals for CO₂ Storage


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Abstract

Permitting, developing and operating a CO₂ storage site all depend on demonstration and ongoing verification of secure containment. Injected CO₂ and displaced brines must remain confined within a specified reservoir interval lest they endanger shallower fresh-water aquifers and/or leak to surface. Historical experience with hydrocarbon exploration and production has proven the capability of geologic seals to retain buoyant fluids on multimillion-year timescales. That experience has also naturally focused attention on certain types of seals, in particular, regionally extensive marine shales, tight carbonates and evaporites. These are the units favoured in hydrocarbon exploration, precisely because they are regionally extensive and reliable, both of which make them relatively easy to characterize and de-risk.

The same properties also make these formations attractive as confinement for CO₂ storage and indeed, all of the projects permitted to date rely on one or more such seals. However, point-source CO₂ emissions are widely distributed across the globe, transport is expensive and geology is variable. There are many highly attractive geologic reservoirs that do not have an easily-characterized overlying regional seal. One such area is the onshore region south of Perth, the site of the proposed South West Hub storage project. Another is the Mississippi River Chemical Corridor in southeastern Louisiana. Both of these areas have excellent reservoirs and significant local emissions sources but only discontinuous (though abundant) geologic seals. We refer to these as “baffled confinement systems” and if their performance could be de-risked, it could both unlock economically significant local storage resources and open volumetrically significant new potential storage resources across the globe.

Analogy with petroleum migration and ground water flow suggests that such confining systems can work. Migration losses and slow propagation of the thermogenic migration front (the limit of thermally-matured hydrocarbons) are well known in petroleum exploration. Similarly, experience with contaminated groundwater (including natural variations in salinity), shows that such spread of the contaminate plume is often slow and always finite. Even without extensive seals, natural variations in geologic properties such as permeability and capillary entry pressure slow fluid movement. Pore throat trapping, dissolution, local capillary trapping and even small buoyant traps, all serve to arrest migration and for limited volumes, ultimately stop spread of the plume as a whole. In principle, the same should be true for injected CO₂. The question is how to predict and quantify the confinement

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capacity of baffled systems, given the details of the local geology.

We focus here on the example of southeastern Louisiana, with the aim of using it as an applied case to discover broadly applicable general principles. Within the depth window for CO$_2$ storage, the geology of this area is characterized by extensive deltaic deposits, including amalgamated channel sands that form excellent reservoirs. Regionally extensive marine shale seals pinch out to the south (down-dip) of the Chemical Corridor, so local confinement relies on the discontinuous muds and coals formed by Miocene channel linings, crevasse splays, floodplains and swamps. Local hydrocarbon accumulations prove that at least some of these are reliable field-scale seals and vertical well logs show that low-permeability facies are abundant. However, predicting specific seals and/or de-risking the performance of the system as a whole is challenging.

We describe the results of a three-pronged effort to quantify and predict the confinement capacity of this system. In the first part, we look at the local geology and use extensive well logs, local hydrocarbon field data and analogue data to create a statistical description of the permeability variations. In the second part, we use physical analogue modelling to investigate the effects of bed-scale permeability variation on the flow and retention of injected CO$_2$. These models serve to inform our view of which variables matter and to calibrate full-physics reservoir modelling, which forms the third part of our work. In this last part, we use thin, fast-running models to experiment with the effect of varying geometric and petrophysical parameters on migration and trapping of fluids at the field scale.

*Keywords:* storage; confinement, seal, confining zone, deltaic reservoir, baffled containment