Simulation Evaluation of Geological Sequestration of Carbon (CO_2) in Saline Aquifers

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Extended Abstract

High demand for fossil fuel and its extensive use in the automotive sector and other industrial engineering processes and plants leave a huge carbon footprint in the environment leading to severe climate changes and global warming, and elevated levels of atmospheric pollution. It is critical to minimize the carbon footprint through industrial scale decarbonization projects to preserve the planet for future generations and mitigation technologies to minimize these impacts of carbon accumulation in the atmosphere. CCUS (carbon capture, utilization, and storage) technologies play a key role in this effort.

The three key elements of CCUS technology include:

- Carbon Capture (at its origin such as from the atmosphere and other industrial carbon emission sources (power plants or chemical manufacturing units)
- Better utilization of emitted carbon compounds (CO_2 and other acid gases) in improving upon various industrial processes and other technology-applications (e.g., conversion to other useful compounds or chemicals)
- Storage and confininement methods for CO_2 and other toxic gases in deep reservoirs and salty brine underground in a safe manner and for extended periods of time (hundreds and thousands of years)

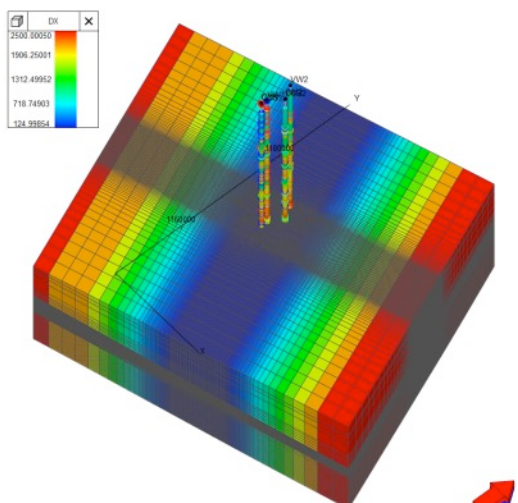
Carbon capture methods fall under three groups.

- Pre-combustion (CO_2 removal before fossil fuel [FF] burning)
- Post-combustion (physical or chemical absorption/adsorption during FF burning)
- Oxy-fuel combustion techniques (burning FF in presence of pure O_2 and water vapor and capturing the resultant CO_2 gas

Carbon utilization strategies employ carbon conversion to renewable fuels, new chemicals (Urea), and advanced materials like carbon nano tubes and graphene; another method of CO_2 utilization is to inject it into oil reservoirs for Enhanced Oil Recovery (EOR). Sustainable storage of CO_2 in saline aquifers and depleted oil and gas reservoirs (both conventional and unconventional) by subsurface injection is becoming more of a practical and preferred approach. Subsurface carbon storage is a highly preferable method to keep carbon out of the atmosphere and minimize unseasonal climate changes and global warming.

The focus of this technical article is the study of carbon storage technologies and the associated challenges, particularly in salty brine reservoirs. Through a series of reservoir simulation studies, we evaluated the technical feasibility, operational efficiency, and commercial scalability of subsurface processes. This type of evaluation guides in selecting suitable reservoirs/salaries for a long term and sustainable CO_2 storage. The main objective of this simulation study is to evaluate the effects of a suite of reservoir, rock and fluid properties, and rock-fluid interactions influencing the subsurface fluid-flow dynamics influencing storage efficiency and long-term sustained storage.

Selection of a model saline reservoir for this study is based on published data on a sandstone reservoir complex in the Decatur area in Illinois Basin. These data are available through DOE's Data Exchange program EDX (DOE EDX, 2021) and (CO2 Data Share Website, 2022). The target reservoir is the saline aquifer of Mt. Simon Sandstone. Reservoir model dimension is 64558 ft x 62289 ft x 3717 ft with grid cells of 126 x 125 x 110. Low permeability shales and mudstones of the Eau Claire Formation overlay Mount Simon Sandstone which serves as a caprock/seal for the reservoir. The reservoir model uses high-resolution Tartan grids within the area of interest with more coarse resolution away from the storage area. The cell size dimensions in the storage area are 125ft x 125ft x ~5 ft. Figure 1 shows the gridding structure of the simulation (dynamic) model.



We selected a suite of reservoir/rock and fluid properties and rock-fluid interaction parameters to conduct this study. Table 1 below shows the selected parameters and their extensive variations in the simulation sensitivity study by appropriate multipliers.

Simulation Study Input Parameters
Reservoir/Rock, Fluid, and Rock-Fluid Parameters Variations

No.	Parameters Evaluated	Base	Min	Max
	Reservoir/Rock			
1	Pore Volume Multiplier	100000	10000	1000000
2	Cap Rock Perosity	1	0.8	1.2
3	Cap Rock Permeability	1	0.1	10
4	Cap Rock Kv/Kh	0.1	0.001	0.5
5	Storage Porosity	1	0.8	1.2
6	Storage Permeability	1	0.1	10
7	Storage Kv/Kh	0.1	0.001	0.5
	Fluid (Brine)			
8	Salinity	100000	10000	300000
	Rock-Fluid Interaction			
9	Imbibition Critical Gas Saturation	0.225	0	0.45
10	Imbibition Gas Corey Exponent	6.2	0	10
11	Imbibition Crirtical Water Saturati	0.397	0.326	0.5
12	Imbibition Water Corey Exponent	1.5	0	10

Table 1. Selected parameters and their range for simulation sensitivity study

The parameters were set to base values reflecting the example reservoir, rock, and fluid properties and the rock-fluid flow parameters based on laboratory measurements. The parameter variations were set using appropriate multipliers applied to the base values as indicated in the Table 1. Injection period covered about ten years from 2011 to 2021 and is based on the historical injection information available (published data). In this period, we accomplished an injection of a total of 2.7 million tons (51.8 BCF) of CO_2 in two wells following published historical data on injection schedule.

Simulation outputs include initial CO_2 plume size, plume expansion rate, plume growth, bottomhole pressure changes, dissolved CO_2 in brine, and both residually and structurally trapped CO_2 saturations. Figures 2 and 3 below display one of the results of CO_2 plume size change with time during the injection and post injection period and a tornado chart that captures brine salinity sensitivity on CO_2 plume size.

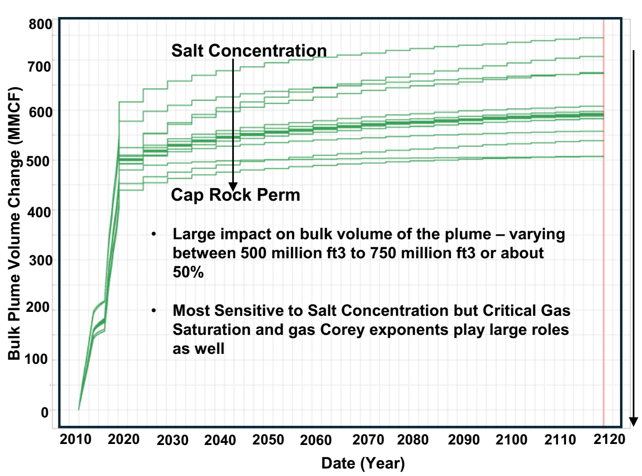


Figure 2. CO_2 Plume Size Change with Time During Injection and Post Injection

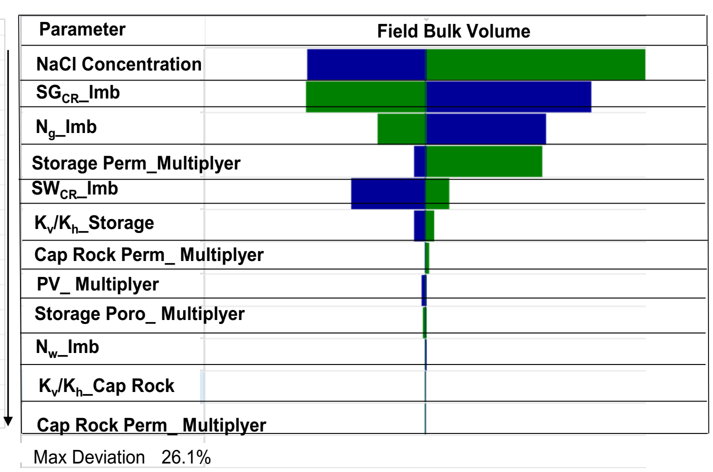


Figure 3. Tornado Chart Showing Parameter Sensitivity

As noted, during the injection period of ten years, as salt concentration increases CO_2 plume size increases by about 50% 500 ft^3 vs 750 ft_3 due to CO_2 solubility decrease in higher concentration brine. After the injection period, the plume-size increase rate flattens and indicates potentially sustainable CO_2 sequestration. In addition to the salt concentration, critical gas saturation and gas Corey exponents play significant role as well in determining the plume size growth.

The results of the study help rank the parameter sensitivities to assess reservoir and aquifer suitability and sustainability for CO_2 storage. Based on these results of ranking of these parameter sensitivities to assess reservoir or aquifer suitability and sustainability for CO_2 storage indicates that aquifer salinity plays a dominant role with critical gas saturation in imbibition relative process, the Corey exponent for gas, the permeability of storage region. All other parameters studied provided in Table 1 have minimal or the least impact. The above four parameters need closer scrutiny in the selection of CO_2 sequestration site.

References

Department of Energy, NETL's Energy Data eXchange EDX, Published Data, (**2021**) *https://edx.netl.doe.gov/dataset/?q=IBD*P

CO_2 Data Share Website, Illinois Basin - Decatur Project Dataset, USDOE, Archer Daniel Midland Co, Trimetric Corp., and SLB (**2022**) *https://co2datashare.org/dataset/illinois-basin-decatur-project-dataset*