Two phase simulation and Bayesian inversion for CO2 storage in porous media

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Introduction and Motivation

CO2 sequestration is a complex multiphysics process, in which multiphase multicomponent flows play critical role. The fact that the CO2 should be stored for many thousands of years implies that full scale experiments are not possible, and computer simulation is the main approach for exploring the feasibility of different CO2 storage options. Various risks exist in CO2 sequestration, the most important being (i) CO2 leakage through cap-rock failure, faults, abandoned wells, (ii) Brine displacement and infiltration into drinking water aquifers. Quantification of the risks and uncertainties is of ultimate importance for the decision makers when evaluating the storage approaches.

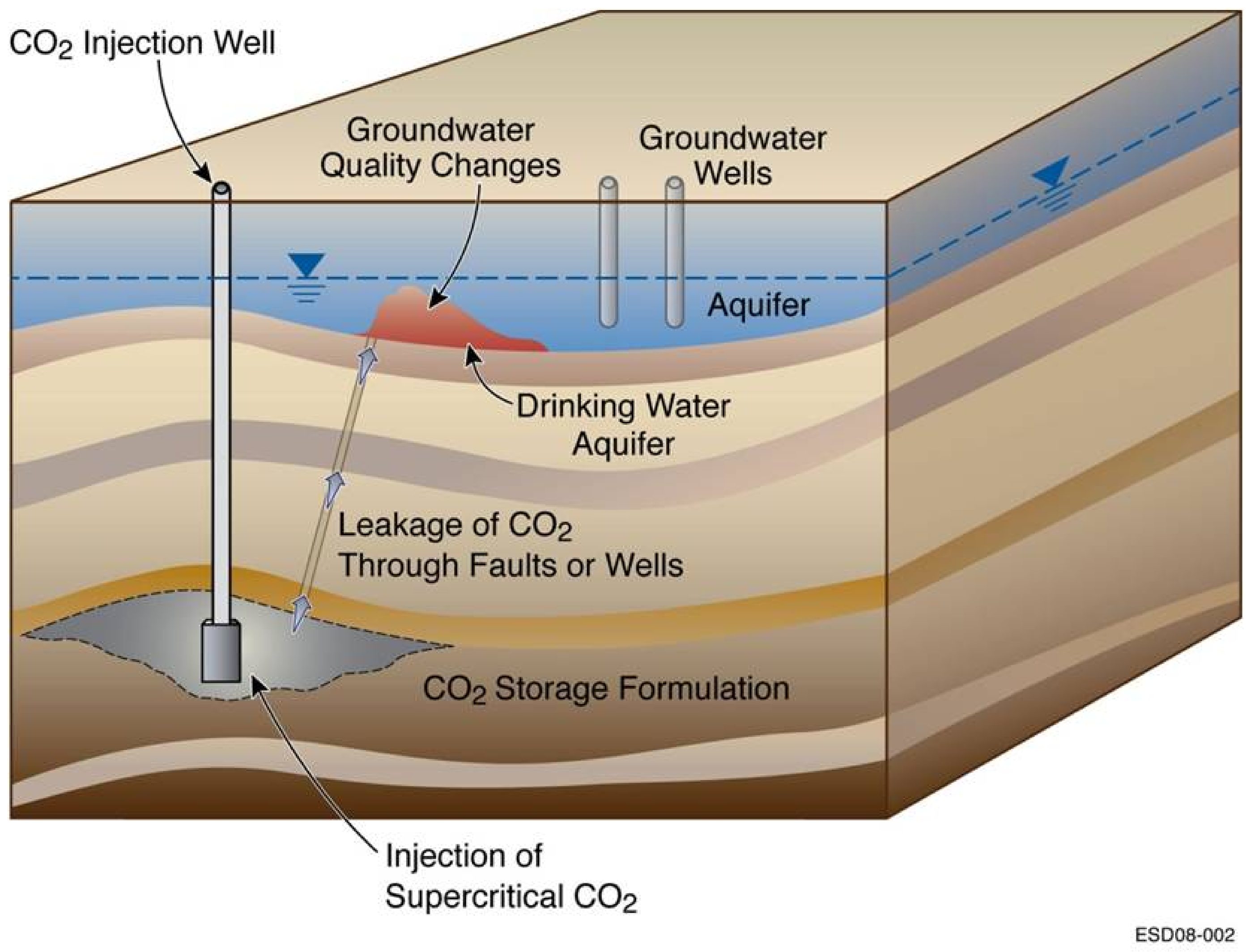


Figure 1: *Picture of ESD*

Parameters are affected by uncertainty (because they are not perfectly known or because they are intrinsically variable). The general objective of our project is to devise effective ways to include, treat and reduce uncertainty in a mathematical model, more precisely to derive, calibrate and validate predictive macroscopic models that incorporates the relevant phenomena. In this work we simulate leakage scenario of CO2 storage, and we estimate the parameters of the macro scale model.

Physical Hypothesis and Model

- 2 phases: brine and CO_2
- Darcy's law for the velocity of each phase
- The capillary pressure between liquid pressure and CO_2 pressure is a non linear function of the liquid saturation $p_c(S_w) = p_n - p_w$
- Phases occupy the entire pore space: $s_w + s_n = 1$
- Mass conservation for each phase

$$\phi \partial_t (\rho_w S_w) + \operatorname{div}(\rho_w \mathbf{V}_w) = Q^w,$$

$$\phi \partial_t (\rho_n S_n) + \operatorname{div}(\rho_n \mathbf{V}_n) = Q^n.$$

Φ = porosity
ρ_α = density of the α phase
s_α = saturation of the α phase
p_α = pressure of the α phase
$\mathbf{V}_\alpha$ = Darcy's law for the velocity
Q^α = source term

Numerical simulation: Leakage of CO_2 from the aquifer through an abandoned well

CO_2 is injected into an aquifer, spreads within the aquifer and upon reaching a leaky well, rises up to a shallower aquifer. A quantification of the leakage rate which depends on the pressure build-up in the aquifer due to injection and on the plume evolution is the goal of the simulation (Figure 2).

The aquifers are initially filled with brine (s_n = 0). The initial conditions in the domain include a hydrostatic pressure distribution which is dependent on the brine density. The lateral boundary conditions are constant Dirichlet conditions and equal to the initial conditions. All other boundaries are no-flow boundaries. CO_2 is injected at a constant rate of 8.87 kg/s and the simulation time is 1000 days.

Figure 3 show the 2D simulation of the benchmark (with in-house code). Figure 4 show the 3D simulation of the benchmark with DuMuX open source [3]. Figure 5 show the CO_2 leakage through the leaky well as a function of time. This is defined here as the CO_2 mass flow at midway between top and bottom aquifers divided by the injection rate, in percent.

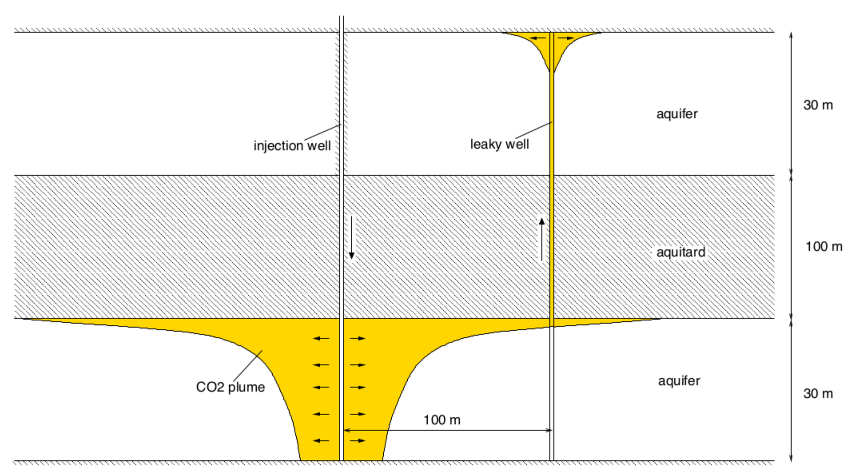


Figure 2: *Scenario of the Benchmark [1, 2]*

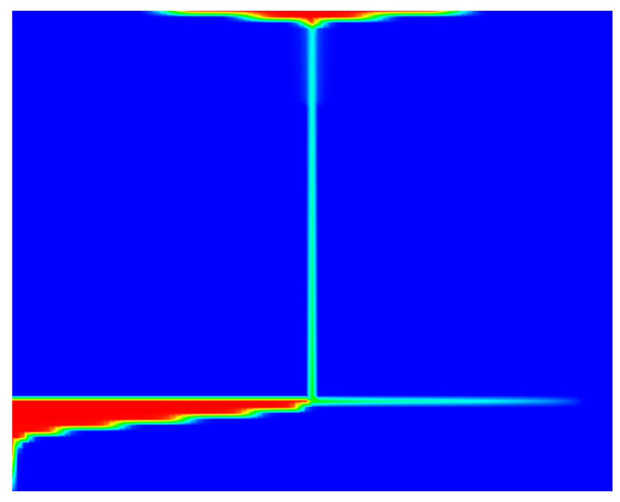


Figure 3: *2D simulation of the benchmark*

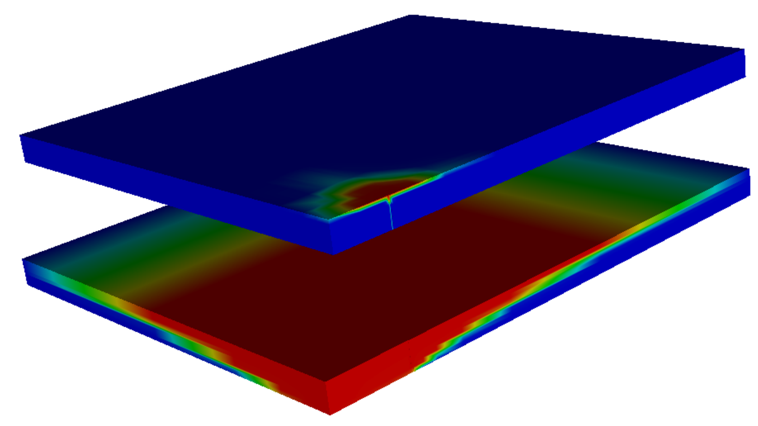


Figure 4: *3D simulation of the benchmark*

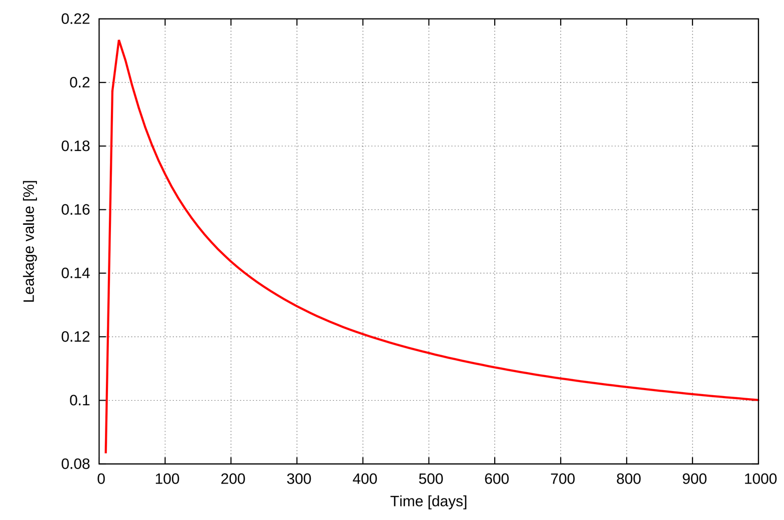


Figure 5: *CO_2 leakage through the leaky well as a function of time*

Bayesian Inversion

The inverse problems can be stated as: Given data D and forward model $\mathcal{F}$, find parameters θ. Bayes' theorem prescribes how to incorporate a priori data and measurements into the model.

$$P(\theta|D) = \frac{P(D|\theta)\, P(\theta)}{P(D)} \qquad \text{Bayes formula}$$

$$P(D) = \int P(D|\theta)P(\theta)\mathrm{d}\theta$$

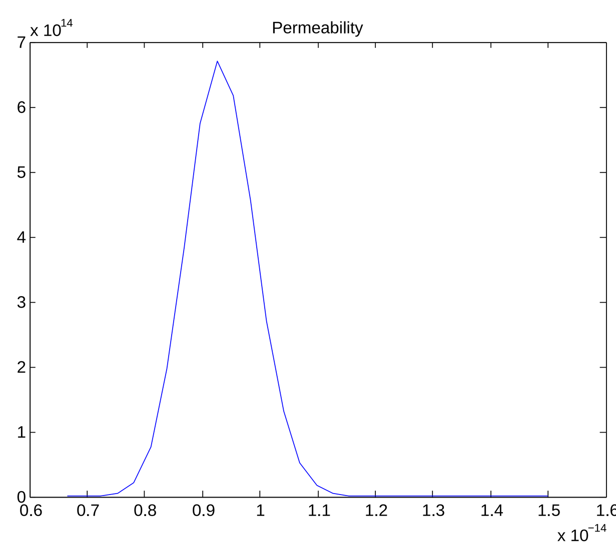
$$D = \mathcal{F}(\theta) + \epsilon; \qquad \epsilon_i \sim \mathcal{N}(0, \sigma^2) \text{ where } \epsilon = \text{noise}$$

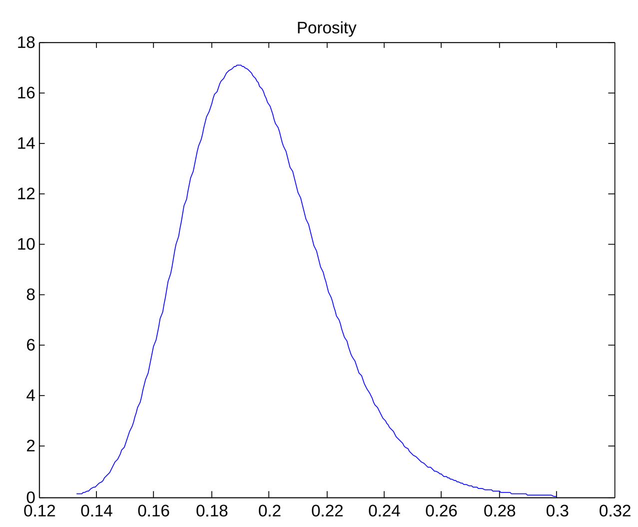
The Bayesian inversion estimates probability distribution of θ. In this case the porosity and the permeability.

- The data are synthetic data with parameters proposed by the benchmark
- $P(\theta)$: **Prior distribution** for the parameter θ can be assumed using available information
- $P(D|\theta)$: **The Likelihood**

Parameter estimation

The porosity and the permeability has been considered as parameters. The a posteriori of both are computed. The effective porosity and permeability is found to be very close to the reference.





References

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[2] Nordbotten, J., Celia, M., Bachu, S., 2005a. Injection and Storage of CO2 in Deep Saline Aquifers: Analytical Solution for CO2 Plume Evolution During Injection. Transport in Porous Media 58(3), 339–360.

[3] DuMuX web-page: http://www.dumux.org

Acknowledgements

This work is supported by SABIC, the Saudi Basic Industries Corporation, one of the world's leading manufacturers of chemicals, fertilizers, plastics and metals.