# EASiTool: An Enhanced Analytical Simulation Tool for Storage Capacity Estimation

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## 1. Introduction

In this study, an enhanced simulation tool was developed that can be used by $CO_2$ sequestration stakeholders in their decision-making process to increase their confidence in investing the geological $CO_2$ storage. The analytical simulation tool

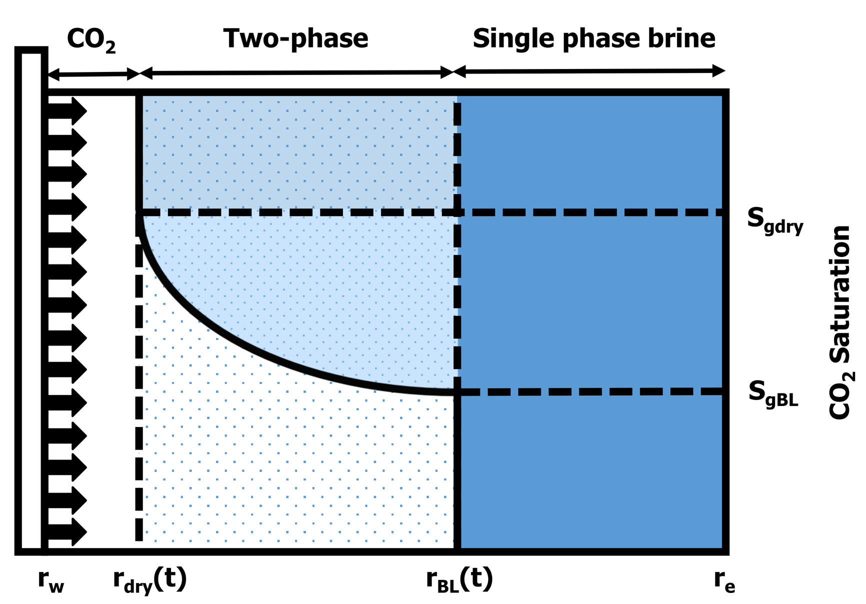
1. provides a science based estimate of storage capacity by applying novel analytical models for both closed- and open boundary aquifers,
2. analyze the possibility of enhancing storage efficiency by integrating brine management (brine-extraction technology),
3. incorporate rock geomechanics as a limiting factor in injectivity calculations, and
4. address uncertainties associated with input model parameters.

The EASiTool can be used to provide reservoir-scale storage-capacity estimates that are based on novel methodologies to calculate pressure buildup in geological formations.

## 2. Analytical Solution of Two-Phase Flow

### 2.1 Assumption

- Fully penetrating vertical well
- Homogeneous
- Isotropic
- Horizontal
- Cylindrical
- Constant rate
- $\mu_j$ and $c_j$ are constant




### 2.2 $CO_2$ Injection in Saline Aquifers

- Infinite acting and closed boundary conditions
- Two-phase relative permeability
- $CO_2$ dissolution into brine
- Formation of drying-out zone around the injector

$$P_{wD} = P_{wD}^S + \sum_{i=1}^{N_w-1} q_{Di}\left[-\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\overline{\lambda_w}}}E_i\left(-\frac{r_{Di}^2}{4\eta_{D3}t_D}\right) + \frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\overline{\lambda_w}}}Ei\left(-\frac{r_{eD}^2}{4\eta_{D3}t_D}\right) + 2\frac{\overline{\lambda_g}}{\overline{\overline{\lambda_w}}}\frac{\eta_{D3}t_D}{r_{eD}^2}exp\left(-\frac{r_{eD}^2}{4\eta_{D3}t_D}\right)\right]$$

$$P_{wD}^S = \frac{1}{2}(ln(t_D) + 0.80908) + S_a + \frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\overline{\lambda_w}}}Ei\left(-\frac{r_{eD}^2}{4\eta_{D3}t_D}\right) + 2\frac{\overline{\lambda_g}}{\overline{\overline{\lambda_w}}}\frac{\eta_{D3}t_D}{r_{eD}^2}exp\left(-\frac{r_{eD}^2}{4\eta_{D3}t_D}\right)$$

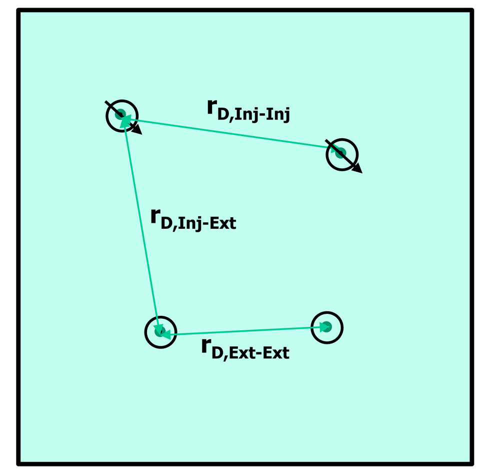
### 2.3 Brine Extraction

- Open boundary $\quad P_{wDExt}(t_{DExt}) = \frac{1}{2}(ln(t_D) + 0.80908)$
- Closed boundary $\quad P_{wDExt}(t_{DExt}) = \frac{2t_{DExt}}{r_{eDExt}^2} + ln(r_{eDExt}) - \frac{3}{4}$

## 3. Analytical Simulation

### 3.1 calculation of $CO_2$ injection and brine production rates

Fracture pressure for $m$ injectors and minimum bottomhole pressure for $n$ extractors:




$$\overline{\overline{A}}.\overline{Q} = \overline{B} \qquad A = \begin{bmatrix} \boxed{Inj - Inj} & \boxed{Ext - Inj} \\ \boxed{Inj - Ext} & \boxed{Ext - Ext} \end{bmatrix}, \quad Q = \begin{bmatrix} Q_{Inj_1} \\ \vdots \\ Q_{Inj_m} \\ Q_{Ext_1} \\ \vdots \\ Q_{Ext_n} \end{bmatrix}, \quad B = \begin{bmatrix} \frac{2\pi hk\overline{k_{rg}}(P_{Frac}-P_i)}{\mu_g} \\ \vdots \\ \frac{2\pi hk\overline{k_{rg}}(P_{Frac}-P_i)}{\mu_g} \\ \frac{2\pi hk\overline{k_{rw}}(P_{MinBHP}-P_i)}{\mu_w} \\ \vdots \\ \frac{2\pi hk\overline{k_{rg}}(P_{Frac}-P_i)}{\mu_g} \end{bmatrix}$$

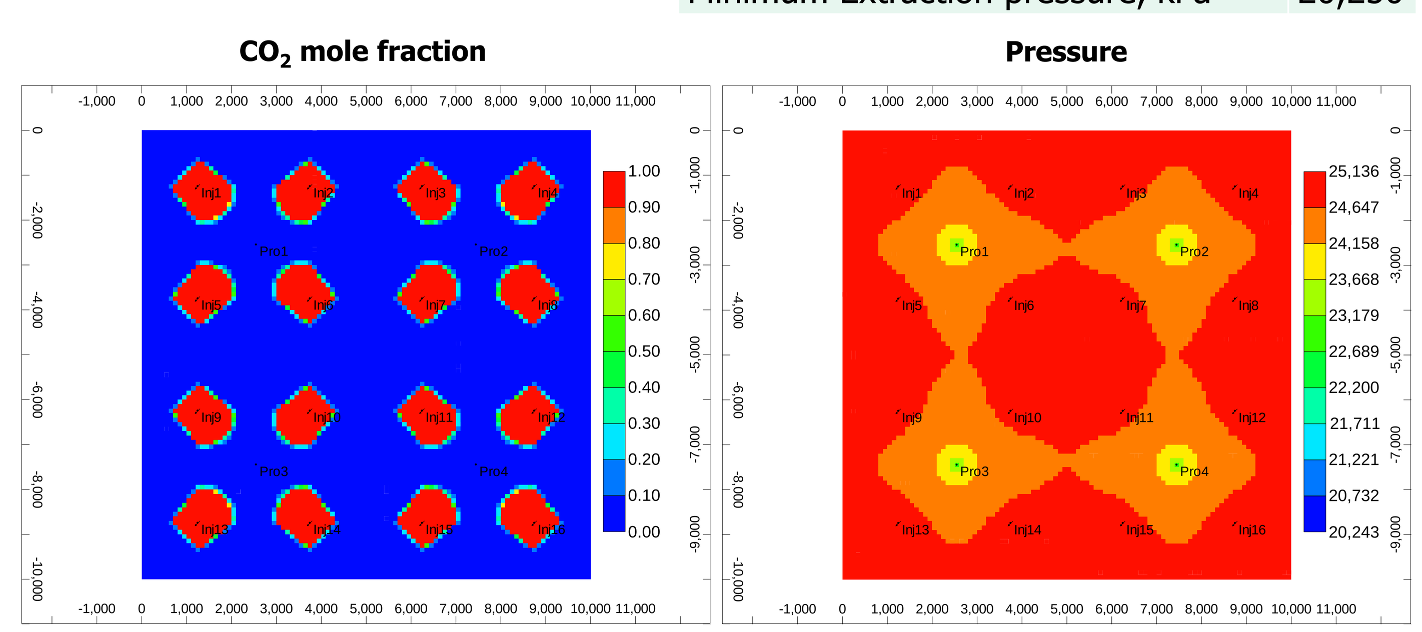
## 4. Optimal Injection/Extraction Rates

### 4.1 Simulation results for 16 injectors and 4 extractors

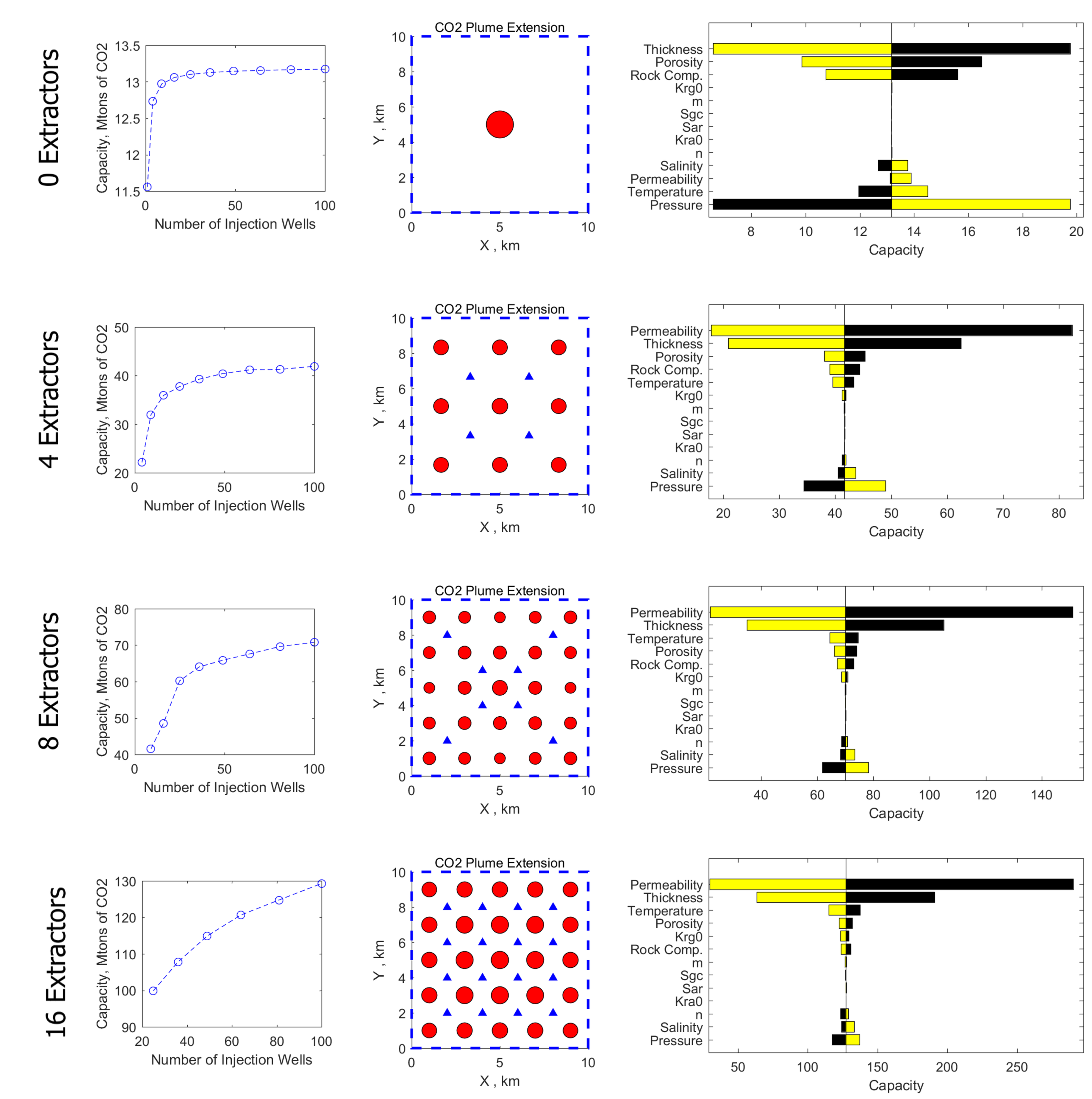
The initial pressure is 20.25 MPa and the target bottomhole pressure of injectors and extractors are 25.25 and 20.25 MPa. The predicted bottomhole pressures after 20 years using same injection and extraction rates by numerical simulations are 25.14 and 20.24 MPa.

| | |
|---|---|
| Initial pressure, kPa | 20,250 |
| Initial temperature, °C | 65 |
| Thickness, m | 100 |
| Salinity, kg/mol | 0 |
| Porosity | 0.2 |
| Permeability, mD | 100 |
| Rock compressibility, 1/Pa | 5.0E-10 |
| Reservoir area, km$^2$ | 100 |
| Basin area, km$^2$ | 100 |
| Boundary Condition | Closed |

| | |
|---|---|
| Residual water saturation | 0.5 |
| Residual gas saturation | 0.1 |
| Water exponent | 3.0 |
| Gas exponent | 3.0 |
| Water end-point relative permeability | 1.0 |
| Gas end-point relative permeability | 0.3 |
| Simulation time, year | 20 |
| Injection well radius, m | 0.1 |
| Maximum injection pressure, kPa | 25,250 |
| Minimum Extraction pressure, kPa | 20,250 |




## 5. Effect of Brine Extraction




## 6. Conclusions

1. Analytical model is a reliable tool for preliminary capacity estimation of saline aquifers.
2. Addition of brine/$CO_2$ phase behavior, two-phase relative permeability model, and near well-bore effects, such as brine evaporation, salt precipitation, and rock geomechanics, allows better injectivity estimates.
3. Brine extraction enhances the storage capacity and controls the pressure buildup.

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