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Dynamics of CO_2-Brine Mass Transfer in Naturally Fractured Reservoirs (NFRs): Implications for Storage Capacity and Predictive Modeling

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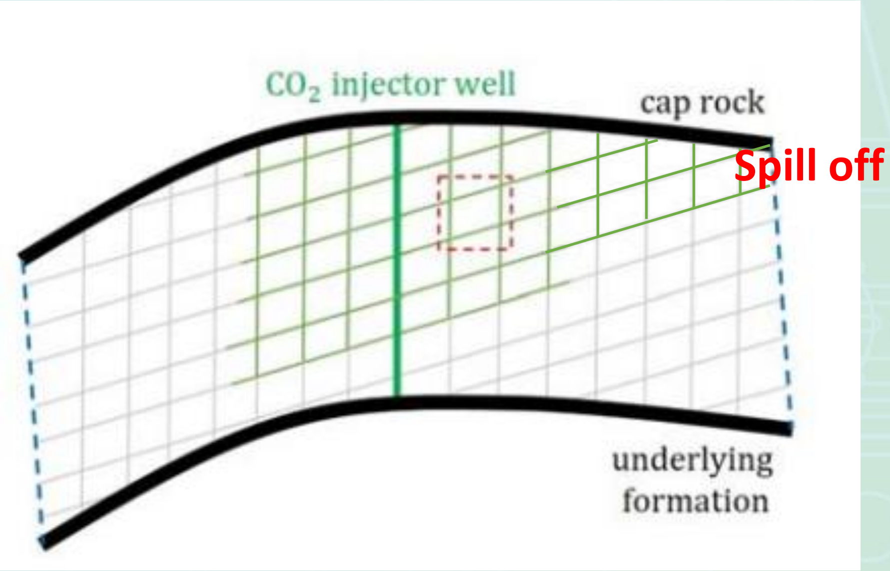
Outline

- Introduction & Objective
- Modeling Approach
- Injection phase
- Post-injection pahse
- Conclusions

Introduction & Objective

- **Naturally fractured reservoirs (NFRs) are ubiquitous**
  - ✓**>50% conventional hydrocarbon resources in fractured carbonate reservoirs**
- **Large contrasts of permeability & entry pressure between fractures and matrix**
- **Challenges of CCS in NFRs:**
  - ✓**Capillary barrier: CO_2 tends to be non-wetting**
  - ✓**CO_2 preferentially flow through fracture network**
  - ✓**Loss of porous matrix storage capacity**
  - ✓**High risk of CO_2 spill-off of anticline**

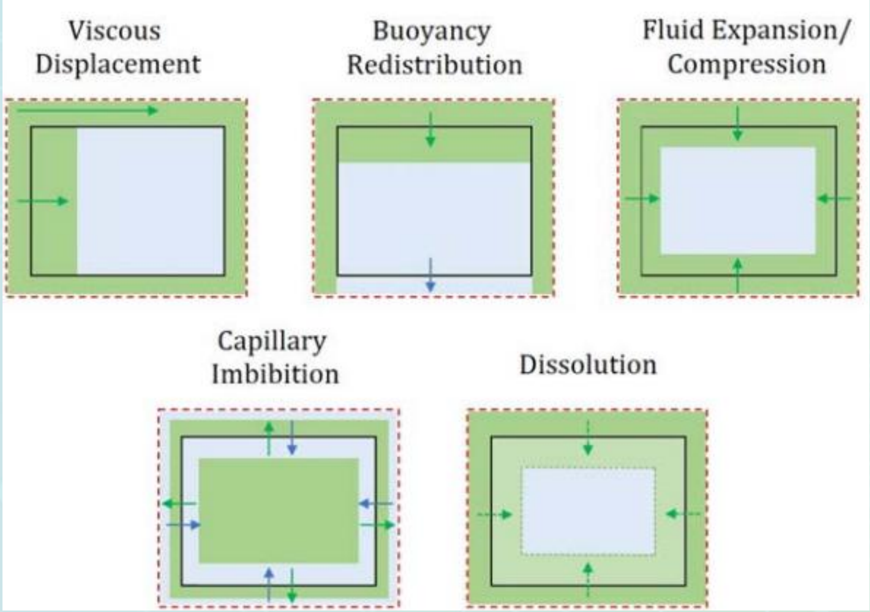
March, R., Doster, F., & Geiger, S. (2018). Assessment of CO2 storage potential in naturally fractured reservoirs with dual-porosity models. Water Resources Research, 54, 1650–1668. https://doi.org/10.1002/2017WR0221



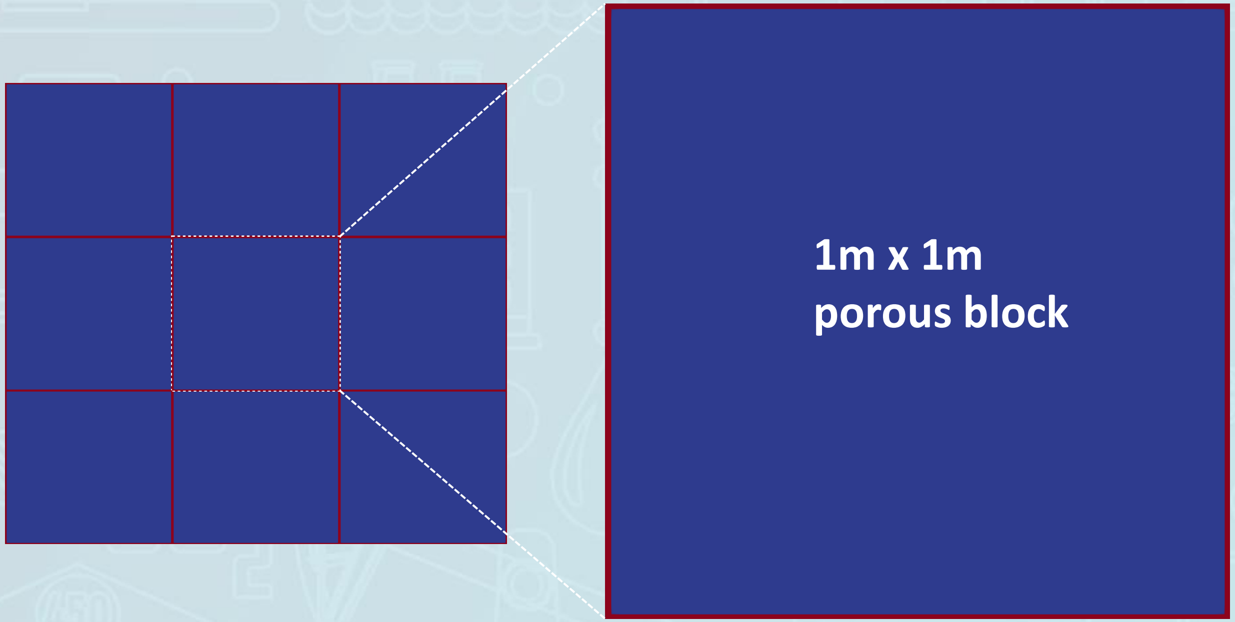
Introduction & Objective

- **Multiple CO_2-brine mass exchange mechanisms:**
  - ✓ **Dominating exchanging mechanisms vary between injection and post-injection phases**
- **Dual-porosity (or dual-permeability) models for reservoir scale simulations:**
  - ✓ **key assumption – mass exchange rate function**
- **This study provides mechanistical modeling of CO_2-brine mass exchange at the scale of matrix blocks**

March, R., Doster, F., & Geiger, S. (2018). Assessment of CO2 storage potential in naturally fractured reservoirs with dual-porosity models. Water Resources Research, 54, 1650–1668. https://doi.org/10.1002/2017WR0221



Modeling Approach



- **Idealized fracture network**
  - ✓ **k=1x10^5 mD (i.e., ~10s μm aperture)**
- **Matrix permeability:**
  - ✓ **0.001 - 100mD**
- **CO_2 "instantaneously" fill fractures**
- **No CO_2 mass in porous matrix initially**
- **STOMP code selected for modeling**

Modeling Approach: Injection Phase

Model domain: 1m-thick vertical slice

- 1m x 1m porous block
- 1cm x 1cm grid resolution
- Brooks-Corey ksp functions:

	K(mD)	S_{w_r}	Entry Pressure head(m)
Fracture	1.0e5	0.05	0.02
matrix	0.001 0.01 1.0 10.0 100.0	0.15 0.15 0.15 0.15 0.15	20.0 2.0 0.2 0.2 0.2

- **In-situ P & T:**
  - ✓**30MPa**
  - ✓**70**°C
- **Initial condition:**
  - ✓$S_{g\_f}=0.95, S_{w\_f}=0.05$
  - ✓$S_{g\_m}=0.0, S_{w\_m}=1.0$
- **BC: fixed CO_2 saturation in fractures:**
  - ✓Mimicking continuous injection

Modeling Approach: Post-Injection Phase

Model domain: 1m-thick vertical slice

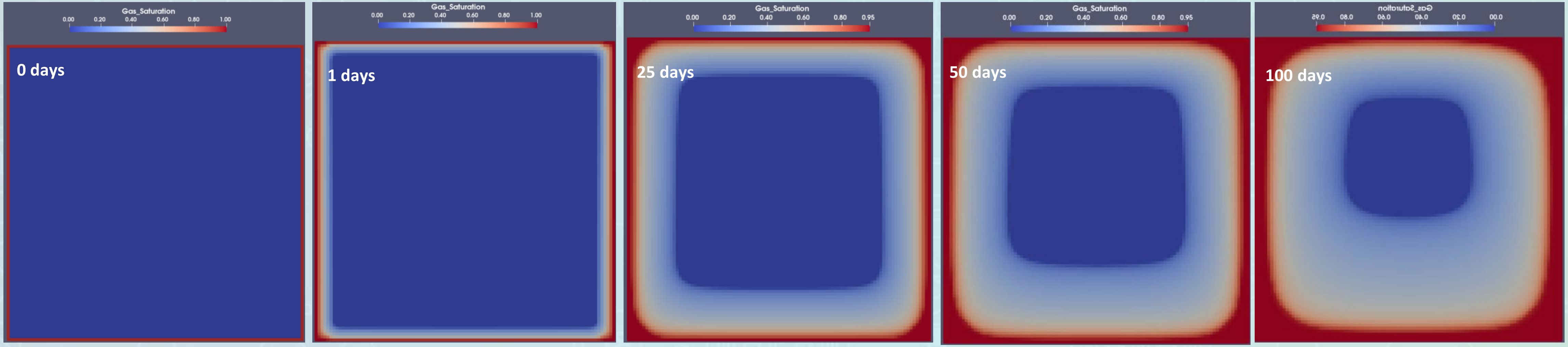
- 1m x 1m porous block
- 1cm x 1cm grid resolution
- Brooks-Corey ksp functions:

	K(mD)	S_{w_r}	Entry Pressure head(m)
Fracture	1.0e5	0.05	0.02
matrix	0.01 0.1 1.0 10.0 100.0	0.15 0.15 0.15 0.15 0.15	2.0 0.2 0.2 0.2 0.2

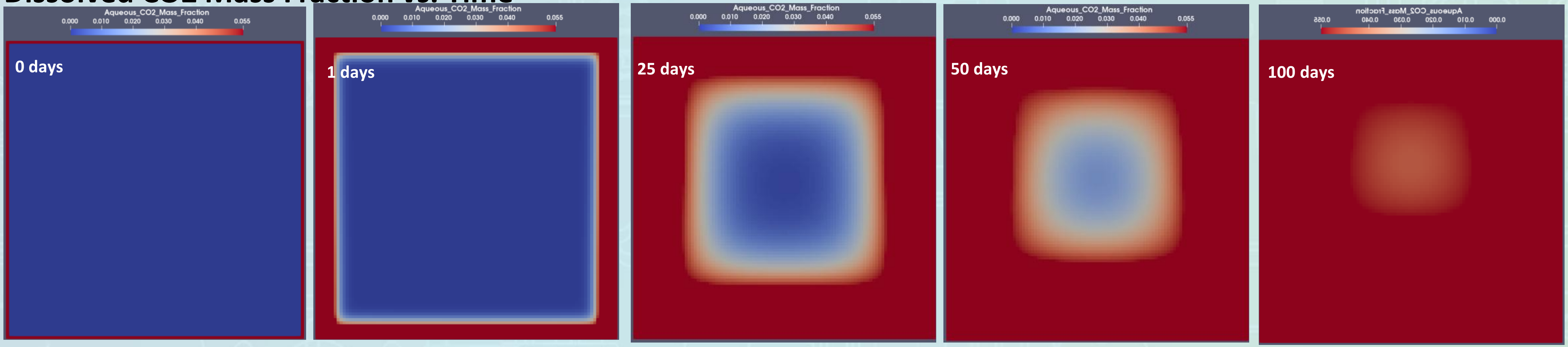
- **In-situ P & T:**
  - ✓**30MPa**
  - ✓**70**°C
- **Initial condition:**
  - ✓S_{g_f}=0.95,S_{w_f}=0.05
  - ✓S_{g_m}=0.0,S_{w_m}=1.0
- **BC:**
  - ✓Left & right - no flow, lateral symmetry condition
  - ✓Top & bottom – hydrostatic inflow/outflow

Simulation Results: Injection Phase (matrix k=1mD)

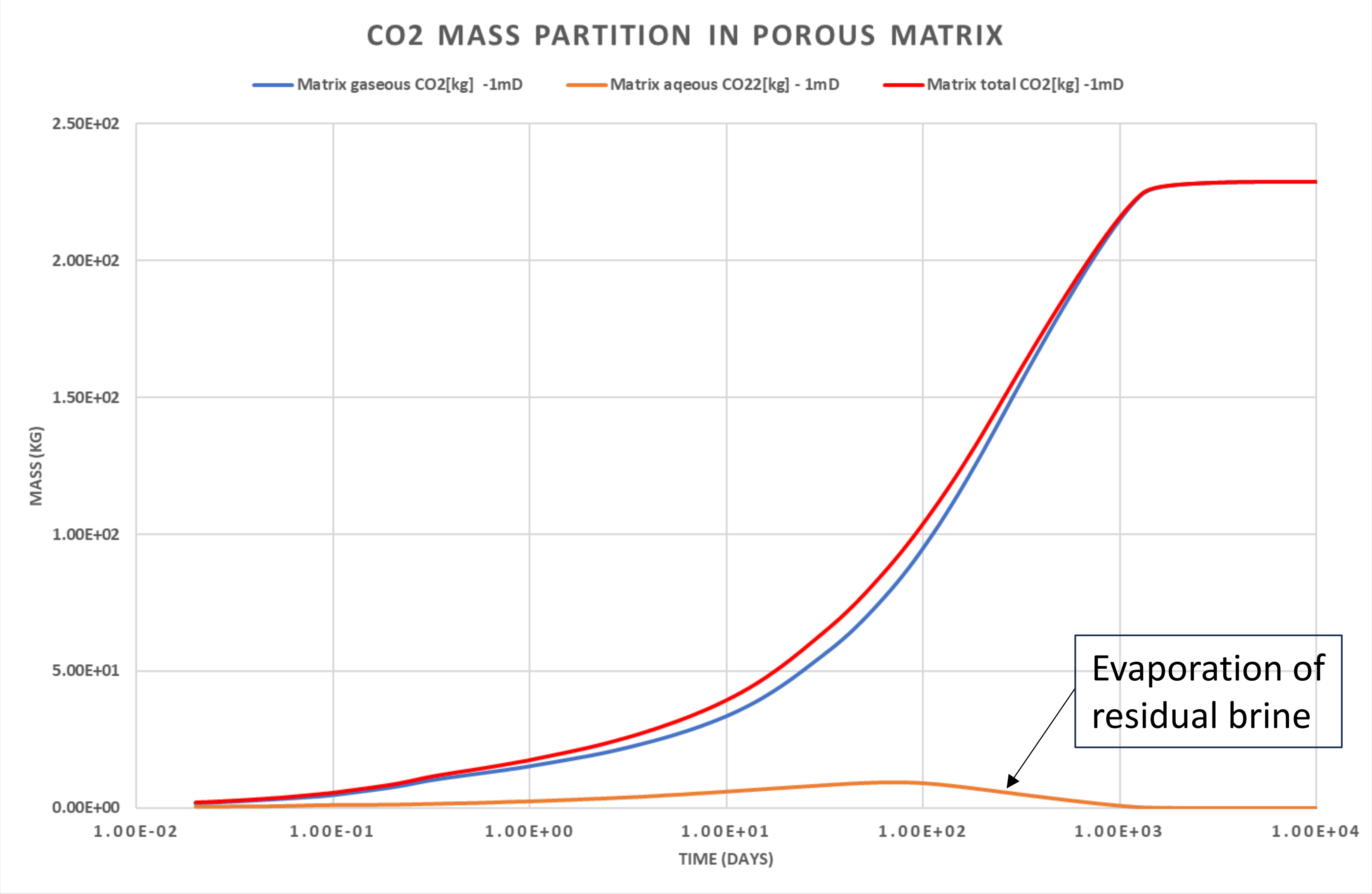
CO2 Gas Saturation vs. Time



Dissolved CO2 Mass Fraction vs. Time

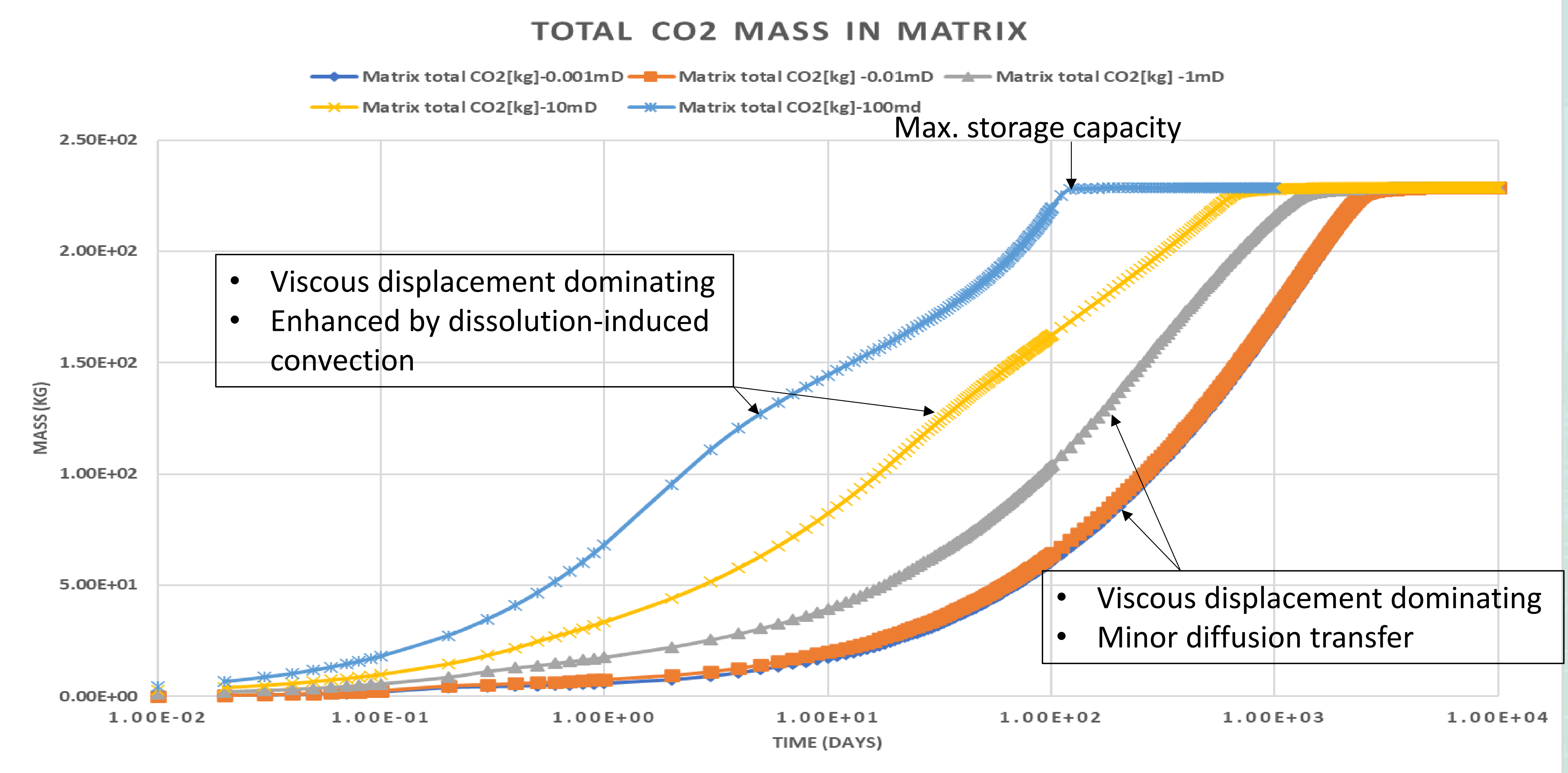


Simulation Results: Injection Phase (matrix k=1mD)



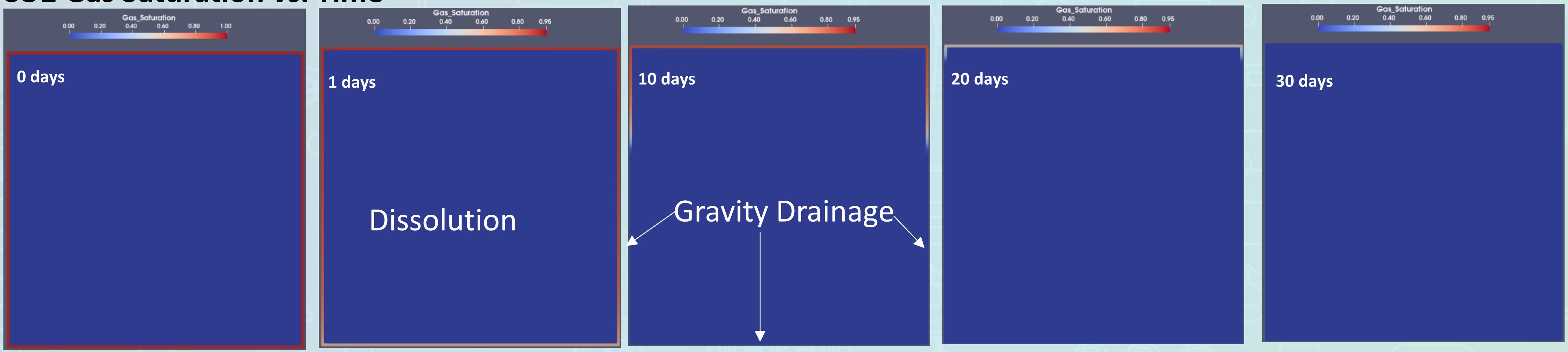
- **Highly nonlinear rate transfer function**
- **Viscous displacement is the dominating mass transfer**
- **Diffusion transport is minor**
- **No observed convective flow inside porous matrix block**

Simulation Results: Injection Phase

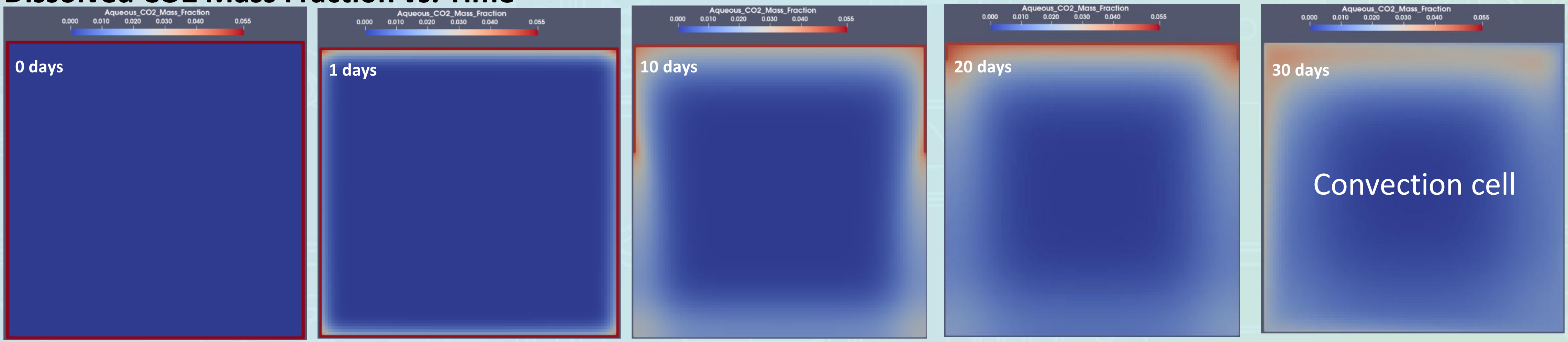


Simulation Results: Post-Injection Phase (matrix k=1mD)

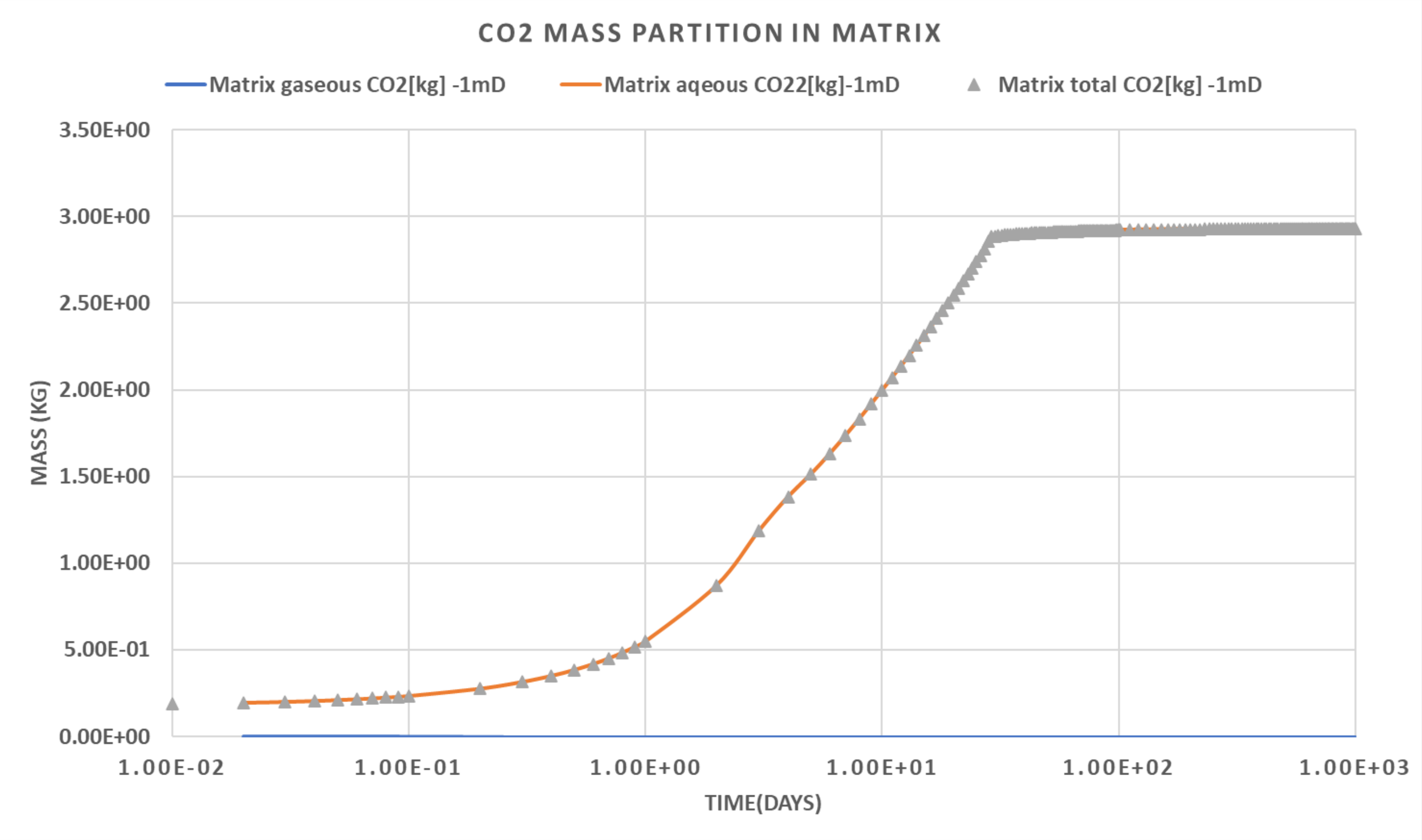
CO2 Gas Saturation vs. Time



Dissolved CO2 Mass Fraction vs. Time

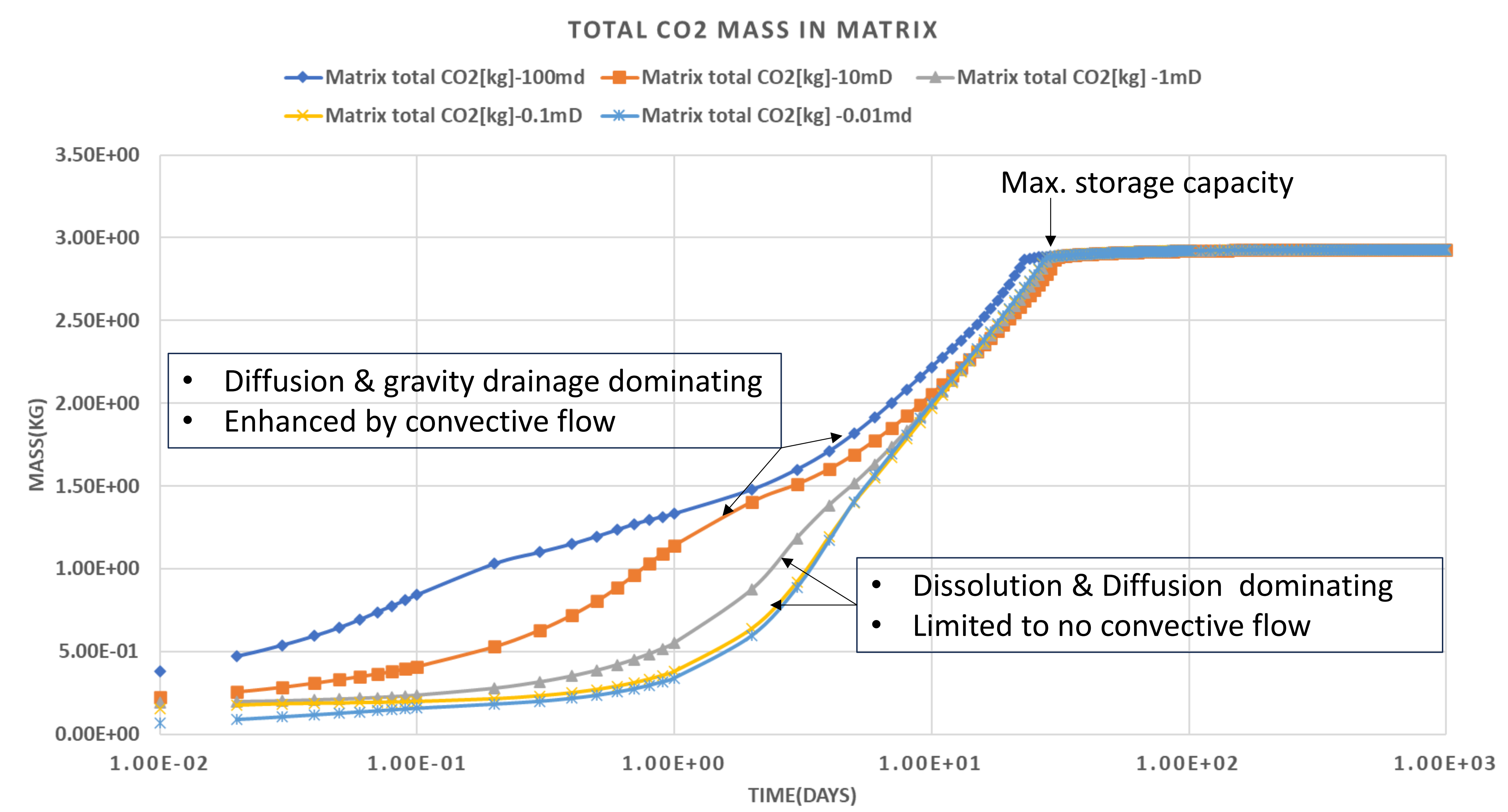


Simulation Results: Post-Injection Phase (matrix k=1mD)



- CO_2 dissolution & diffusion dominating mass transfer
- Convective flow contributing to mass transfer
- No viscous displacement transfer for moderate to low permeability matrix rock

Simulation Results: Post-Injection Phase



Conclusive Remarks

- Viscous displacement dominates CO_2 mass transfer into matrix from fractures during injection phase
- Dissolution-diffusion and gravity drainage processes dominate fracture-matrix CO_2 mass transfer during post-injection phase
- Field applications of CCS in NFRs require the development of more robust fracture-matrix transfer rate functions for CO_2-brine system
- Designing optimal CO_2 injection rate into NFRs should consider the time scales of reaching maximum storage capacity of rock matrix