Multiscale Modeling of Carbon Dioxide Migration and Trapping in Fractured Reservoirs with Validation by Model Comparison and Real-Site Applications

Project Number DE-FE0023323

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U.S. Department of Energy
National Energy Technology Laboratory
Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting
August 13-16, 2018
Presentation Outline

• Modeling approach
• Mass transfer functions
• Diffusion
• Vertically-integrated approach
• Key findings
MODELING APPROACH
What are the issues
Dual domain concept

Physical geometry

Idealization: the dual-continuum representation
Modeling approach

Fracture
\[ \frac{\partial m^f_\alpha}{\partial t} + \nabla \cdot (\rho^f_\alpha u^f_\alpha) = \rho^f_\alpha Q^f_\alpha + T^{fm}_\alpha \]

Matrix
\[ \frac{\partial m^m_\alpha}{\partial t} = \rho^m_\alpha Q^m_\alpha - T^{fm}_\alpha \]

F = Fracture grid-block
M = Matrix grid-block
TF = Transfer function
MASS TRANSFER FUNCTION
Gravity Drainage

\[ V_{CO_2}(t) = V_{CO_2}^{max}(1 - e^{-\beta t}) \]
Spontaneous Imbibition
Anticline model
Fractured - Unfractured

**Fractured Anticline**

CO₂ Plume in the Fractures

CO₂ Plume in the Matrix

**Unfractured Anticline**

**Stored Mass of CO₂**

- Unfractured Model
- Fractured Model

![Graph showing stored mass of CO₂ over time](image)
DIFFUSION
Diffusion Mass Transfer

Matrix Shapes
Simplified Approach

\[ M_d = \begin{cases} 
  a_1 \sqrt{T_d} + a_2 T_d + a_3 (T_d)^{3/2} & T_d \leq T_{d0} \\
  1 - \sum_{j=1}^{N} b_{1j} \exp[-b_{2j} T_d], & T_d > T_{d0} 
\end{cases} \]

\[ M_d = \frac{M_t}{M_\infty} = \frac{C_t}{C_0} = C_d \]

\[ T_d = \frac{Dt}{l^2} \]
Accuracy/Consistency
SIMPLIFIED MODEL
Simplified models

• Fractures:
  – High permeability
  – Low capillary entry pressure
• Vertically-integrated sharp-interface model
• Pressure and saturation reconstruction for mass transfer
Test Case

1500m

50m
100 mD fractures

VE-Dual Porosity
Fracture Domain
$k_f = 100$ mD

VE-Dual Porosity
Matrix Domain
$k_m = 10$ mD

3D-Dual Porosity
Fracture Domain
$k_f = 100$ mD

3D-Dual Porosity
Matrix Domain
$k_m = 10$ mD

CO$_2$ Sat.
1000 mD fractures

VE-Dual Porosity
Fracture Domain
$k^f = 1000$ mD

VE-Dual Porosity
Matrix Domain
$k^m = 10$ mD

3D-Dual Porosity
Fracture Domain
$k^f = 1000$ mD

3D-Dual Porosity
Matrix Domain
$k^m = 10$ mD

CO$_2$ Sat.

CO$_2$ Sat.
Key findings

- We can use relatively simple deterministic models to describe mass transfer based on:
  - Diffusion
  - Gravity drainage
  - Spontaneous imbibition
- Vertically-integrated models seem to be applicable
Accomplishments to Date

• Development of transfer function for dual-porosity model for both spontaneous imbibition and gravity drainage
• Implemented and validated single- and two-phase dual-porosity modules and a hysteresis module for MRST
• Updated TOUGH2/ECO2N simulator for better performance for CO$_2$ storage in fractured media simulations
Accomplishments to Date

• Investigated the impact of matrix block connectivity on CO$_2$ storage capacity
• Developed analytic solutions for CO$_2$ storage due to diffusion of dissolved CO$_2$
• Developed and implemented a vertically-integrated dual-porosity model
• Investigated development of vertically-integrated dual-permeability model
• Conducted sensitivity analyses based on new models
Lessons learned

• More complex is not necessarily better
• Vocabulary matters
Synergy opportunities

- The modeling approaches developed in this project should be useful to other projects studying carbon sequestration in fractured formations
Future Plans

- Continue development of vertically-integrated dual-porosity and dual-permeability models
- Continue to investigate the impact of fracture and matrix block parameters on CO$_2$ storage capacity
- Apply newly developed modeling approaches to In Salah site
THANK YOU!

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Appendix
Benefit to the Program

- **Goal:** Develop new capabilities for carbon sequestration modeling in fractured reservoirs through improvements in the representation of fracture-matrix flow interactions.

- Support industry’s ability to predict CO$_2$ storage capacity in geologic formations to within ±30 percent.
Project Objectives

- Develop new models for interactions of fracture and matrix flow
- Incorporate those models into reservoir-scale simulators
- Conduct sensitivity analyses of trapping efficiency and storage capacity using new model
- Apply new model to In Salah site
### Gantt Chart (BP1-BP3)

**light grey: accomplished; dark grey: planned; MS: mile stone**

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<th>Fiscal Year</th>
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# Gantt Chart (BP4)

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• Geiger, S. (2016). Talk presented at the Foundation CMG summit in Calgary, Canada

Bibliography 10


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