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UQ-CCSG Annual Research Review
Centre for Coal Seam Gas
2018

Dynamic simulation for gas injection

T. McCourt[1], F. Zhou[4], V. Bianchi[2], D. Pike[3], D. Donovan[1] [dmd@maths.uq.edu.au]
[1]The University of Queensland, School of Mathematics & Physics [2]The University of Queensland, School of Earth & Environmental Sciences
[3]Memorial University of Newfoundland, Canada, Department of Mathematics & Statistics [4]Arrow Energy, Brisbane Australia

INTRODUCTION

Scientific Problem: Within carbon storage, the spatial distribution of the subsurface reservoir and its internal architecture, such as irregularly distributed baffle zones and stratification, can affect preferential CO_2 migration pathways. Thus the effect of subsurface geological features must be carefully analysed. This is a challenging aspect of numerical simulation, which requires irregular grids to capture the architecture. Currently few injection simulations account for differential grid geometries.

Methods: A new approach is proposed for simulation runs with varied grid geometries, comprising of both different stratifications and baffle zones. The modelling approach proposed by this study can be used for simulations at different scales and specifically for permeability upscaling of strongly heterogeneous reservoirs.

OUTCROP

LINEDRAWING

INTERPRETATION

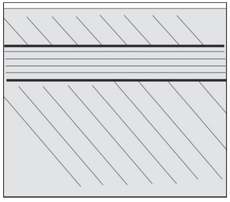
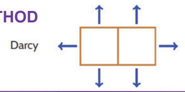


Photo courtesy of Matthias Klawitter

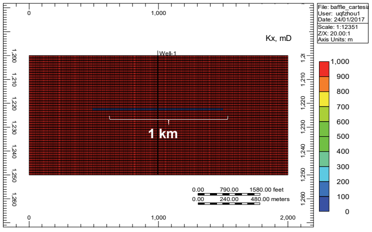
STANDARD INJECTION MODEL

METHOD



Standard injection model based on Darcy's equation: If two adjacent sites have equal pressure, Darcy's equation will predict no flow across their common boundary.

SIMPLE ARCHITECTURES



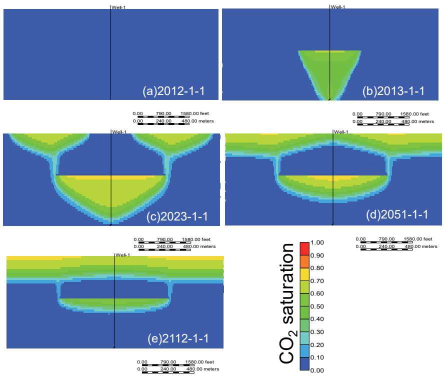
2D model developed in GEM, a compositional simulator in CMG™
Built in 200×50 cells
Grid size in x-direction: 10 m
Grid size z-direction: 1 m

The baffle zone is 1km and 1 m in length and height respectively.

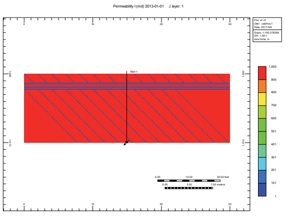
The permeabilities of the model are 1000mD and 0mD for high permeability and baffle media respectively.

CO_2 was injected at the bottom of the grid with a constant bottom-hole pressure of 15MPa.

Injection of CO_2 was stopped after 10 years, while the model ran for a further 90 years to allow for inspection of the migrating CO_2 plume.

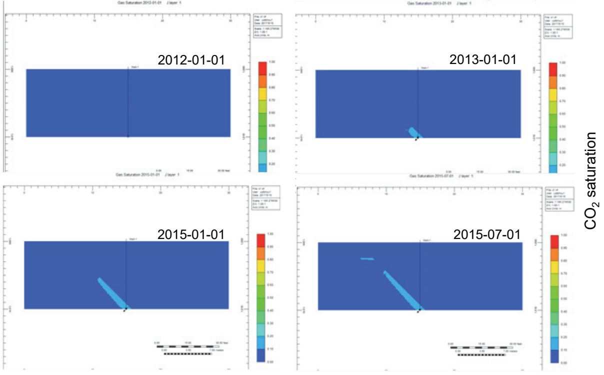


COMPLEX ARCHITECTURES



A 2D model with dimension of 30m by 1m by 10 m in x-y-z directions. The grid size is 0.1m. The initial reservoir pressure is 10 MPa and the injector will be constrained by BHP of 15 MPa and maximum injection rate of CO_2 of $0.2m^3$ per day. The baffles are inclined in 45 degrees.

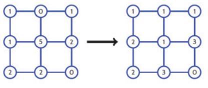
SIMULATION:8 hours of running for 3 yrs simulation



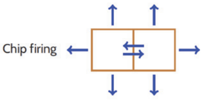
CHIP FIRING INJECTION MODEL

A reservoir is modelled as a grid of cells or sites capable of storing CO_2. Movement of CO_2 is possible between sites that are connected by edges (representing, cleat, fractures, etc.). The CO_2 is simulated as discrete packets, with movement governed by threshold dispersion (through chip firing) and dispersion effects from depth dependent pressure gradients.

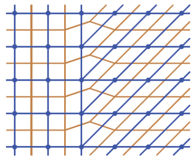
A critical site value C_{crit} is assigned to each site. If a site accumulates more than C_{crit} packets of CO_2, some number of packets are dispersed to (edge) connected sites.



Central site fires



In the case of chip firing, if the same number of chips are present at two adjacent sites, either they are both below C_{crit} and no flow occurs, or they swap an equal number of packets, this is equivalent to no flow occurring.

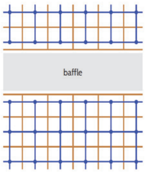


Subsurface structure with sites and edges shown

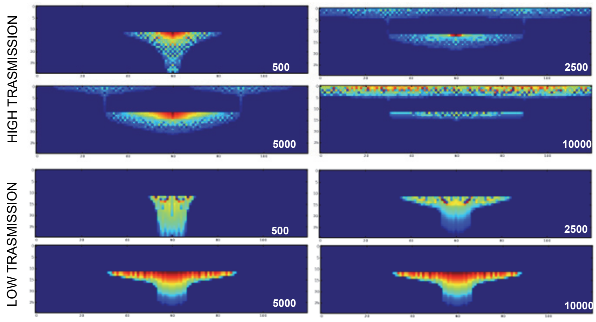
Variables that are fixed across all the architectures are:
- Number of rows R = 30.
- Number of columns C = 120.
- Baffle length B = 60 (running from column 30 to 90).
- Baffle width 2 (from row 10 to 12).
- Critical site value C_{crit} = 5 times the edges connected to the site.

Exceptions for a square grid are,
C_{crit} = 2 times the edges to test 'easy transmission'
C_{crit} = 20 times the edges to test 'inhibited transmission'

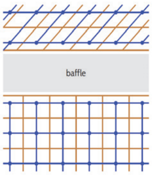
SIMPLE ARCHITECTURES



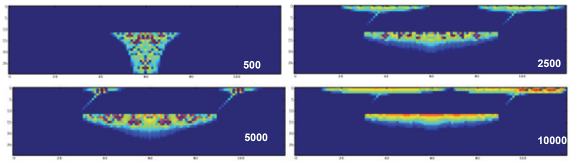
Site Capacity	
3	▒
6	🟦
9	🟩
12	🟨
15	🟫
18	🟥



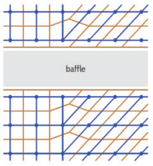
COMPLEX STRATAL ARCHITECTURES



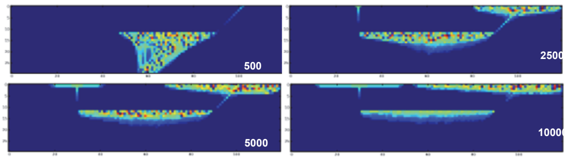
Different internal stratification



COMPLEX STRUCTURAL ARCHITECTURES



Fractured zone



Advantages:

- Time efficiency
- High flexibility architecture
- Useful for upscaling

FUTURE GOALS:

The potential is for fast and efficient mechanisms to capture the effect of differing internal strata architecture on single phase and multi-phase flow regimes. *Graph theory* is used to encapsulate the different architectures and *chip firing* captures the horizontal movement and upward motion with a depth component to simulate the flow regime of real world reaction/diffusion systems.
Future plans include incorporating additional physical properties for the study of more complex architectures on which to trial this modeling technique.

Acknowledgements

This research has been conducted using academic software licenses provided by CMG Limited.