Reservoir Modelling and Geomechanics of Hydrogen Storage at the CO2CRC Otway International Test Centre

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[Image of reservoir model with labels Naylor, CRC-1, CRC-2, NAYLOR, NAYLOR SOUTH-1]
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- $124.5M Programme

Australia’s Future Energy Resources:
A Project within EFTF to understand energy resource potential

- Gas, oil, and CO₂ geological storage potential in underexplored basins
- Hydrogen storage and sources
- CO2-EOR in residual oil zones
- Basin inventory

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Aims of Otway H2 Storage Study

- Use the Naylor Field at the Otway International Test Centre as a template for reservoir and geomechanical modelling of H2 storage

- Model the multicyclic injection of hydrogen into a depleted gas field and identify any flow related or geomechanical risks

- Conduct extensive sensitivity analysis (cushion gas, diffusion, methanogenesis, temperature etc)

- Compare hydrogen injection to model runs using CO2 and methane to identify any key differences.
Naylor Field

- Fault-bound anticline, with sealing faults on 3 sides of the structure
- Gas field in production until 2003
- Used by the CO2CRC from 2007 as a CO2 storage pilot project
- Hydrogen injection and production in this study is conducted near crest of anticline
- ECLIPSE models constructed in 2006 by CO2CRC are the foundation for the H2 modelling

Berard et al., 2008
Initial Reservoir Simulations without Geomechanics

- Ensure modified grid performs close to reference grid
- Conduct sensitivity analysis for different parameters (cushion gas, diffusivity, dissolution, methanogenesis)

- Reservoir volumetric rate of 1500 m$^3$/d for both injection and production
- 2 injection production cycles
- 1 month shut in between
- 40 days N2 cushion gas
Importance of Cushion Gas

- $N_2$ cushion gas ensures efficient delivery of $H_2$ gas
- Constrains $H_2$ to crest of anticline
- Initial $N_2$ cushion gas is used for later geomechanical simulations
H2 Storage vs CO2 (Injection)

- N2 cushion gas initially fills crest of structure
- CO2 sinks to lower reservoir levels and displaces N2 laterally
- H2 remains at crest of structure
H2 Storage vs CO2 (Production)

- Little CO2 produced relative to H2 and significant cushion gas is extracted.
- CO2 remains in lower portions of reservoir, which is favourable for CO2 storage.
- H2 is produced very efficiently, with most cushion gas remaining in reservoir.
H2 Storage vs CO2 (Production)

- Subsurface behaviour of CO2 and H2 result in large differences in gas recovery
- H2 recovery improves with successive cycles
H2 Storage vs CO2 (Pressure differences)

- Injection and production rates for CO2 are highest due to greater density change.
- Field pressures are the same for all 3 gases.
- Bottom hole pressure for CO2 slightly larger due to greater viscosity.
Geomechanical model

- Dynamic moduli using sonic and density logs
- Calibration of elastic properties using rock mechanical testing
- Stress orientations from previous mechanical studies
- Magnitude of maximum horizontal stress determined by iterative matching of synthetic borehole image to observed borehole features
Geomechanical Model Embedment

- Dynamic moduli using sonic and density logs
- Calibration of elastic properties using rock mechanical testing
Dynamic Geomechanical Model Runs

- Mostly run at standard injection and withdrawal rate
- More cycles than uncoupled reservoir modelling
- Other parameters varied: thermal properties, injection rate, fault properties, gas type

<table>
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<th>CASE ID</th>
<th>Fluid</th>
<th>Rate (m3d)</th>
<th># Cycles</th>
<th>ECL thermal</th>
<th>VIS thermal</th>
<th>Fault Prop</th>
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<td>FA 90%</td>
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</table>
Temperature Effects

- Greatest geomechanical anomalies are driven by colder gases being introduced to a warm reservoir.
- Different gas densities with depth lead to different thermal signatures for the different gases.
- Injection rate for H2 is lower, therefore more equilibration with host rock.
- CO2 requires high injection rate to meet 1500 m3/d flux at depth, therefore lower T at depth.

<table>
<thead>
<tr>
<th>Injectant type</th>
<th>Reservoir volumetric injection rate (m3/d)</th>
<th>Surface injection rate (sm3/d)</th>
<th>Bottom-hole pressure (bar)</th>
<th>Bottom-hole temperature (°C)</th>
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<tr>
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Temperature Effects

- Temperature change in reservoir is greatest for CO2 case
- H2 injection produces a smaller anomaly
- Thermal pulse propagates into the overlying caprock
Reservoir Deformation

- Little reservoir deformation observed for H2 storage case
- Negative deformation occurs for CO2, even during pressurisation
- For CO2 thermal effects are stronger than the pressure effects
Impacts of Thermal Contraction on Fracture Pressure

- Fracture pressures depend on confining stress
- Cooling in wellbore region reduces confining stresses and facilitates fracturing.
Thermally Induced Fracturing

- Thermal effects can depress fracture pressures below the wellbore pressure
- Effects are greatest for CO2 models
- Fracture pressures are also depressed in transition zone and caprock
- Reducing injection and production rate significantly reduces thermal effects by allowing greater temperature equilibration
Fault Reactivation

- Thermal contraction and associated elastic relaxation results in plastic deformation along nearby faults
- Effects are much larger for CO2 than for H2
- Neither case reaches > 1% shear strain, which is empirically determined critical value
Key Observations

Geomechanics

- Model runs using CO2 reach slightly higher pressures near the wellbore than H2 and CH4, for same injection rate at reservoir level
- H2 exhibits least thermal cooling at reservoir level due to lower surface injection rates (highest formation volume factor)
- Thermally induced reservoir deformation is small for H2 injection, relative to CO2
- Thermal effects near well bore can reduce fracture pressures to critical levels
- Fracture pressures also modified in cap rock
- Reservoir deformation can also lead to plastic deformation on fault planes
Key Observations

Reservoir Simulations

- Presence of N2 cushion gas is important; constrains H2 to crest of anticline and improves deliverability
- Sensitivity models involving H2 dissolution, diffusivity and methanogenesis make insignificant difference
- H2 and CH4 remain near crest of anticline, while CO2 sinks through N2 cushion gas
- H2 recovery rate from each injection-production cycle is approximately 70-80%
- Up to 56% of the N2 cushion gas is produced by the 10th cycle