Effects of Heterogeneity on CO$_2$ Storage in a Saline Reservoir: A Case Study from Nagaoka Pilot CCS Site in Japan

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Outline

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   • Monitoring activities
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   • Logging data and property modeling
4. Numerical simulation
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Background

- Detailed site characterization is critical for successful geological storage of CO$_2$.
- Heterogeneity of sedimentary facies has strong effects on migration of CO$_2$ (e.g. Sato et al., 2011).
- Injection and monitoring data can be used for the site characterization with heterogeneity (e.g. Doughty et al., 2008).
- Nagaoka pilot-scale CO$_2$ injection site can be used as a case study of the geological modeling with heterogeneity.

- Build a Nagaoka geological model with heterogeneity
- Compare the simulation results with the monitoring data
Nagaoka CO₂ injection site

Well configuration at the reservoir level

- OB-3: 120m
- OB-4: 60m
- OB-2: 40m
- IW-1: Injection site

Formation dip: 15°

- Injection Period: 2003/7/7 ~ 2005/1/11
- Injected amount: 10,400 ton
- Injection rate: 20 ~ 40 ton/day

- Injection layer (~ 1100m)
  - Thickness: 12m
  - Porosity: 23% (ave.)
  - Permeability: 7mD (ave.)
  - Temp./Press.: 48°C / 11MPa
Monitoring programs at Nagaoka site

Pressure measurements

Time-lapse well logging  > CO₂ Saturation

Cross well tomography  > Plume
Results of a 3D seismic survey

Seismic image (NW-SE direction)

-→ anticline structure

Feature along NS direc.

<- depositional process

Framework modeling

Time slice

(~1000ms)

1.5km
Log data and up-scaling for modeling

Permeability logging at 4 boreholes

Layer continuity, but with heterogeneity.

Extrapolate properties to the framework model
⇒ Random Function Gaussian Simulation (RFGS)
Porosity, Permeability distribution

Porosity

Permeability

Sand

Shale
Capillary pressure, relative permeability functions

- Obtained from mercury injection tests
- Low GR: Sand, High GR: Shale

van Genuchten model (no hysteresis)
# Summary of a Nagaoka model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value / Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of layers (Z direc.)</td>
<td>14</td>
</tr>
<tr>
<td>Mesh size (Horizontal direc.)</td>
<td>5m, 10m, 50m</td>
</tr>
<tr>
<td>Active cells</td>
<td>58,856</td>
</tr>
<tr>
<td>Permeability Porosity distribution</td>
<td>Calculated by RFGS</td>
</tr>
<tr>
<td>Anisotropy in the permeability</td>
<td>$K_x = K_y \times 0.4$, $K_y = K_y$, $K_z = K_y \times 0.1$</td>
</tr>
<tr>
<td>Capillary pressure function</td>
<td>From mercury injection test</td>
</tr>
<tr>
<td>Relative permeability function</td>
<td>van Genuchten model</td>
</tr>
<tr>
<td>Simulator</td>
<td>TOUGH2+ECO2N</td>
</tr>
</tbody>
</table>
Pressure and CO$_2$ saturation (results 1)

Pressure at IW-1 and OB-4

CO$_2$ saturation at observation wells
Pressure and CO$_2$ saturation
(results 2: different sand/shale distribution)

Pressure at IW-1 and OB-4

CO$_2$ saturation at the observation wells

Breakthrough time was delayed at OB2.
Results of the simulation (CO$_2$ distribution)

1.6yr (stop injection)  
3yr  
6yr

CO$_2$ distribution in the most permeable zone (top view)

CO$_2$ plume migrates to up-dip direction during the post injection phase.
Comparison to the tomography results

Cross-well tomography between OB2 and OB3 (CO₂ injection stopped)

Simulation results (CO₂ saturation)
Summary

- A geological model at the Nagaoka site was constructed.
  - Heterogeneity by RFGS, Facies dependent properties.
- Behavior of the CO$_2$ plume was simulated using the constructed reservoir model.
  - History matching
- The results of the numerical simulation was consistent with the monitoring observations.

Future Work

- Obtain the best matched parameters and improve the geological model of Nagaoka site.
Acknowledgements

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• We thank BRGM which allows us to use Tough2lBox (Audigen et al., 2011) for constructing MESH files of TOUGH2.

• We thank staff of ENAA, INPEX, GSC, and RITE involved in Nagaoka pilot-scale CO₂ injection project.
Pressure and \( \text{CO}_2 \) saturation (results 3: horizontally isotropic)

Pressure at IW-1 and OB-4

\( \text{CO}_2 \) saturation at the observation wells
Heterogeneity related to sandy/shaly rock