The feasibility of CO$_2$ storage in the off-shore P18 depleted gas reservoir (EEPR-ROAD)

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Introduction

ROAD
Rotterdam Storage and Capture Demo

RCI/CCI/GCCSI
Rotterdam Climate Initiative
Clinton Climate Initiative
Global CCS Institute

P18

CATO₂
Dutch National CO₂ Capture, Transport, and Storage R&D Program

www.co2-cato.nl
Why P18?

The scale, location and maturity of the P18 gas reservoirs make it a good candidate for early commercial demonstration of the potential of Carbon Capture and Storage (CCS).

- **Location**: 20 km N-W of Rotterdam
- **Operator**: TAQA
- **First Production**: 1993
- **Reservoirs supported**: Gas: P18-2, P18-4, P18-6
- **Connected platforms**: P15-D gas processing platform
- **Number of gas wells**: 6
- **Production Horizon**: Bunter sands
- **Theoretical CO₂ storage**: 41 MMton
- **Gas Production**: 16” pipeline to P15-D
- **Type of installation**: 4 Legged steel jacket
- **Function**: Production and transfer of wet gas to P15-D processing platform.
Workflow for a feasibility study

- Data availability
- Geological analysis
- Reservoir modeling analysis
- Geochemical analysis
- Geomechanical analysis
- Well integrity analysis
- Migration path analysis
- Monitoring plan
P18 Description

- Approximate depth: 3500
- Triassic Main Buntsandstein Subgroup (249-245 Ma):
  - Hardegsen (good permeability)
  - Detfurth (low permeability)
  - Volpriehausen (low permeability).
- Primary seal: siltstones, claystones, evaporites and dolostones
- Highly faulted formation
- Hydraulically isolated compartments
  - P18-2
  - P18-4
  - P18-6
- Initial pressure: 340-377 bar
- Temperature: ~120 ºC.
Phase 2: Detailed assessment

P18 Cluster
Geological analysis

P18 is a complex structure, difficult seismic interpretation

Uncertainty exists in geometry, porosity & permeability distribution, $S_w$

Example: P18-4: Uncertainty fault location of 50m (1 voxel) accounts for volumetric uncertainty of 0.5 BCM
Geological analysis

Observations:

- Reservoir quality of the Hardegsen (25m) is good, rest has poor reservoir quality

- Seals:
  - Top and base: thick claystones
  - Lateral: reservoir bounding faults (through juxtaposition)
  - Overburden: Altena claystones >500m & Vlieland claystones (>100m)

- Dynamic GIIP: 17.22 BCM.
- Static GIIP (lower): 15.39 BCM
  - Uncertainties in geometry, porosity & permeability field, $S_w$
Reservoir modeling analysis

- High uncertainty in static model (GIIP)
  - Geometry
  - Porosity / Permeability
  - \( S_w \) (relative permeability / capillary pressure)

- High permeability multipliers used in the history matching process, especially in P18-6

- Results need to be interpreted with care because of these uncertainties
## Injection Capacity

**Figure 27**: Injection behaviour of compartment P18-4, with average injection rate of 1.1 Mton/year.

<table>
<thead>
<tr>
<th>Cumulative CO₂ injected</th>
<th>Units</th>
<th>P18-2</th>
<th>P18-4</th>
<th>P18-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic simulation Study</td>
<td>GNm³</td>
<td>14.7</td>
<td>0.7</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>Mton</td>
<td>29.1</td>
<td>1.3</td>
<td>8.1</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>15.4</td>
<td>30.4</td>
<td>8.1</td>
</tr>
</tbody>
</table>
Reservoir simulation: Non-isothermal and compositional
(Shell simulator: Mores)

CO₂ injection (T)

Radial coordinate system

Small grid sizes

Injection rate: 1.1 mtpa  res P=20 bar

Scenario 1 super critical injection: FBHT=12.3 °C
2 liquid injection: FBHT =-14 °C

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Scenario 1

$t=0$

$t=1$ year after:

$T=\sim 123 \, ^{\circ}C$

$<100 \, m$ after 1 year
Scenario 1

- High temperature gradients
- Potentially thermo fractures
- Possibly some hydrates at higher reservoir pressures

Scenario 2

- Very rapid and local cooling
- First grid adjacent to well drops to 0°C within hours
- Can not be handled by current simulators
Geochemical analysis

Main observations:

- **Decrease of the pH of the formation water**
  Initially to values between 3 and 3.5 (CO$_2$ dissolution)
  Mineral buffering to values between 4 and 5 after years (carbonate reactions) up to thousands of years (full mineral suite)

- **Drying out of near-well area during injection (Reactive transport modeling)**
  Radius depends on the CO$_2$ amount, injection period etc.
  Salt precipitation

- **Porosity changes**
  Negligible after years to decades
  Significant after thousands of years
  Reservoir: decrease of 0.3 pp (from 8.8% to 8.5%)
  Caprock: increase of 0.2 pp (from 1.0% to 1.2%)

- **Impurities**
  Presence O$_2$ has no significant impact on the results

- **Notes**
  Long-term uncertainties are substantial

- **Geochemical impact on geomechanical integrity (compaction)** not yet taken into account
Geomechanical analysis

- the risk of caprock fracturing
- the risk of fault re-activation and slip leading to induced seismicity and CO2 migration
Geomechanical analysis

Observations:
Top seal integrity and fault stability do not represent critical factors

• Combined poro-mechanical effects, due to pore pressure increase, and the thermal effects, due to injection of cold CO₂ into the hot reservoir, may cause **locally hydro-fracturing** of the reservoir rock and possibly, the top-and side seal.

• Lab tests suggest a very high strength for the top seal, but plastic deformation may occur locally at the edges of depleting/expanding compartments.

• The boundary faults of all three compartments are found to be sealing.

• The effects of production and subsequent CO₂ injection on seabed deformation are minor. The maximum production-related **subsidence** amounts to **5 to 7.5 cm**.
Well integrity evaluation

Cement sheath across

Primary caprock

Secondary caprock

Production casing and liner

Tested OK?

Cr13?

Production tubing and completion

Production packer

Wellhead

Abandonment plugs

End-of-well report available

Verification required

Annular pressure

Packer operating envelope

Wellhead and elastomers
Potential migration path analysis

Scenarios:
1. Overfilling the reservoir
2. Migration to aquifers in the overburden, caused by:
   1. fault reactivation
   2. wellbore shortcut

Overfilling the reservoir:

- P18-2: migration towards the Q16-4 structure (arrow 1) and/or the P16-FA field (arrow 4)
- P18-4: in combination with migration along faults could lead to migration towards the P15-E and P15-14 field (arrow 3)
- P18-6 migration towards the P15-10 field (arrow 2).
Potential migration path analysis

Migration to aquifers in the overburden

- Migration of HC identified by bright spots
- HC source Posidonia shale
- Migration via fault plane
- Lateral migration via Brussels Sand into Upper North Sea Grp, or direct via fault.
Monitoring plan

Philosophy of the monitoring plan:

• Crucial to monitor the reservoir pressure

• If irregularities are witnessed additional monitoring is proposed concerning:
  – The well integrity (eg. logs)
  – The overburden (eg. seismic)
  – The seabottom (eg. acoustic and/or via sampling)

• In the current plan no monitoring wells are absolutely required
Questions?