Lessons learned from the CO$_2$ Storage Project at Snøhvit

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Statoil’s CCS projects
An Industrial Approach to Climate Change

- Building up our knowledge and experience (R&D)

- Sleipner
- In Salah
- Snøhvit LNG
- Test Centre Mongstad
- Mongstad Full-scale

Application to new challenges (CCS Business)
Statoil’s CO₂ Storage Sites

Unique blend of
• Offshore/onshore
• Shallow to larger depth
• Horizontal/vertical wells
Phase Behaviour at Operating Conditions

Down-hole gauges would be nice … … and now we have one at Snøhvit!
CO₂ Injection Performance

16.5 Mt CO₂ stored so far (2010)
The Snøhvit LNG/CCS Project, Norway

• Snøhvit (Snow White) is an LNG project, in the Barents Sea offshore Norway.

• CO₂ is captured onshore and transported in a 153km subsea pipeline to a subsea template.

• The CO₂ is injected at a depth of 2600m into the Tubåen formation (below the gas reservoir).

• Injection of CO₂ started in 2008, and so far 1.0 Mt have been stored.
Snøhvit: Key Statistics

- CO₂ injector line: 153 km
- Seabed depth: 330 m
- One CO₂ injector
- Injected gas is ~99% CO₂
- Injected into Tubåen Fm at 2430-2600m depth
Snøhvit injection well

Depth map of base Tubåen Fm.

Perforated zones
Snøhvit CO₂ monitoring

Modelled CO₂ saturation and pressure increase

Amplitude changes

Eiken et al, 2010 (GHGT10)
Snøhvit Flow Modelling

- Currently working on improved model and history match
- Example shows CO₂ plume distribution at 2030 for different fault seal scenarios

With fault juxtaposition but no seal  With disconnected faults
The generic Eclipse radial model

- Two radial models were created:
  - Low resolution 10x2x215
  - High resolution 100x2x215
- Model size: radius = 100 m
  height = 107.5 m
- PVT, relperm properties and saturation endpoint values are from the existing Snøhvit compositional model
- Static properties are average core and log data as base case. Properties were scaled up for generic comparative studies
- Generic thermal properties are taken from similar cases
- Salt saturation and salt properties are taken from available literature
The radial reservoir models

Base case

High resolution
Salt precipitation and CO$_2$ plume

Base case

High resolution

SOLID

CO$_2$
Generic studies on analogues

• History matching:
  - Assisted history matching using in-house software to quantify the effects of property uncertainties prediction
Operating the Sleipner CO₂ Project

1. Monitoring Data:
   - Wellhead pressure and flow rate is monitored continuously
   - Gas composition samples are taken intermittently
   - Several Time-lapse (4D) seismic surveys:
   - Several Gravimetric surveys
     • 2002, 2005, 2009

2. Key Uncertainties:
   - Role of internal Utsira shale layers
   - Reservoir and wellbore modelling
   - Long-term storage capacity
Sleipner CO₂ Project Time-lapse Seismic Data
Sleipner CO\textsubscript{2} seismic monitoring

Top layer

All layers

Injection point

Time [ms]

Increasing amplitude

1 km

2008
Sleipner Modelling Insights

• Initial models built from pre-injection seismic:
  ➢ Coarse grid simulations which indicated a circular, dispersed plume.

• 4D monitoring data indicates a northerly extension to the plume propagation.

• IP modeling (Permedia Migration tool) gave closer matches to the seismic, indicating a dominance of gravity/buoyancy forces over viscous forces.

• Adjusted inputs to conventional reservoir simulations in order to capture enhanced gravity segregation and understand physio-chemical processes:
  ➢ Gives better matches to seismic
  ➢ Shows importance of Vertical Equilibrium (VE) assumption
  ➢ Implies dissolution was previously overestimated

• Results presented in SPE Paper 134891, Singh et al, 2010.
  ➢ Now released as a reference model via IEA-GHG
Conclusions

• At Sleipner and Snøhvit, single wells have successfully injected 0.4-0.9 million tons of CO₂ per year.

• Surface geophysical and well pressure monitor data give rich information on the storage behaviour:
  ➢ Dynamic modelling is better constrained, but still challenging.
  ➢ Indicates strong gravity segregation and minimal dissolution

• The actual plume development has been strongly controlled by geological factors which we learned about during injection.

• High-quality monitor data lowers the detection threshold for any potential leakage:
  ➢ 4D seismic monitoring confirms no leakage into the overburden.

• Detailed site characterization, reservoir monitoring/modelling and well solutions have allowed us to quantify the storage capacity and field performance:
  ➢ Gives a good basis for scoping and optimizing future projects.
Thank you