Towards Hydrogen storage in offshore sandstone reservoirs

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Outline

• Hydrogen storage SOA

• Well integrity challenges

• The RCN HySTORM Project

• The RCN HyLINE Project
State-of-the-art of hydrogen storage

- Onshore storage
  - Associated with offshore wind power (Denmark)
- Salt cavern storage
  - Caverns carved / leached out
  - LRC: lined rock caverns
  - Challenges: liner material choice and rock mechanics during dynamic operation (Hybrit Pilot – Vattenfall)
- Mixed H₂ – CH₄ storage
  - Or use of N₂ as cushion gas
- Large research projects
  - Angus+ (D), Underground Sun Storage (A)
H₂ exposure SOA – relevance to well integrity

- Underground Sun Storage (A)
  - Investigate resistance of steel grades L80, P110, 42CrMo4 QT, 42CrMo4 QTT, L360 and P235 to gaseous hydrogen
  - Slow strain tensile tests at 1 and 12 bar
  - Constant stress during up to 720 h
  - Ageing of steel samples at 25 °C & 1 bar
  - Cement cores exposed to H₂ for 2-14 months
  - Portlandite converted to vaterite, but also occurring in contact with N₂ and CH₄
  - Insignificant change in permeability

Tensile test rig with pressure chamber
H₂ embrittlement SOA – relevance to well integrity

- Kanezaki *et al.*, 2008:
  - Cyclic tensile test of steel exposed to H₂
  - Comparison of fatigue crack growth
  - Specimens cathodically charged with hydrogen over 700 h
  - Pre-straining of specimens to encourage martensitic transformation
  - Crack growth from prepared 100 µm hole
  - Cycles at 260 – 280 MPa; 1-5 Hz
  - Transformed martensitic accelerates hydrogen diffusion in austenitic stainless steels
  - Hydrogen accelerated the fatigue crack growth rates
  - Fatigue crack growth rates of specimens pre-strained at low temperature significantly increased by hydrogen
Bai et al., 2014:

- Similar concerns to development of leakage pathways from wells as in CCS
- Need for tests of Hydrogen diffusion in cement
- Corrosion tests on steel components
- Embrittlement of steel may lead to failure at lower pressure than for UGS
- Steel with higher nickel content (>12%) and presence of nitrogen gas can prevent hydrogen permeation
- Addition of binders of low silica concentration is recommended to avoid permeability increase of hydrogen in cement when water saturation changes
SINTEF's HySTORM project

• Main objective:
  – Perform initial fundamental studies to assess the feasibility of using depleted reservoirs on the Norwegian Continental Shelf as storage sites for high-purity hydrogen

• Secondary objectives:
  – Study NCS caprock material and assess to which degree it can retain H2 and for how long. Include potential detrimental effects of geochemical reactions and cyclic site operations.
  – Study NCS reservoir rock material with focus on how H2 dissolves and diffuses within it (including typical in-place brines relevant for the NCS).
  – Use modelling to upscale experimental results and study potential leakage through caprock defects, with input from experimentally deduced accurate thermophysical properties of H2-rich mixtures.
HySTORM Work Packages

- Post-doc:
  - μfluidics at Uni Oslo (H. Hellevang)
  - LB & MD at QMUL (E. Boek)

**WP1: Gas-rock interactions (UiO, SINTEF, QMUL)**
- Reservoir & caprock samples
- Nm-scale H₂ shale diffusion

**WP2: H₂ reservoir flow (SINTEF)**
- Gas mix properties
- Coupled flow-geochemistry

**WP3: Caprock containment (SINTEF, NORCE)**
- Cyclic load effects
- Leakage through larger caprock defects

**WP4: Feasibility assessment (All)**
- Overall conclusions
- Project management
- Dissemination

MRST coupled geochemical / flow simulations with added linear elasticity

Autoclave exposure of four shale samples within a heating cabinet

Cyclic loading of a hollow cylinder shale specimen
SINTEF's HyLINE project

- Safe Pipelines for hydrogen transport (2019 – 2023)
- Establish knowledge about hydrogen effects on pipeline steels to enable safe and efficient subsea pipeline infrastructure for large-scale transport of hydrogen gas

- H entrance
- H diffusion & trapping
- H effect on properties
  - Structure
  - Strength/ductility
  - Fracture resistance
  - Fatigue

- Standards and guidelines
New national research infrastructure for testing under H₂ gaseous conditions (2021-2022)

Macro-mechanical lab
- Servo hydraulic, 50kN test machine
  - 200°C, 500 bar H₂ atm
  - Visual access to high pressure H₂ tests (window).
  - Dynamic and static loading
  - Infrastructure for HSE and on-site production and compression of H₂ gas

Analytical lab
- Thermal Desorption Spectrometer for detailed measurements of lattice and trapped H in metals.
- H permeation cell for diffusion analyses in H₂ gas.
- High pressure high temperature H charging.

Digital infrastructure
- Material databases
- Multiscale modelling framework

Nano-mechanical lab
- High-pressure hydrogen chamber equipped with a nano-indenter
- Plasma focused ion beam microscope (PFIB) with full characterization setup
- Hydrogen plasma charging facility
Technology for a better society