Experimental investigation of coupled processes affecting caprock seal integrity for CO2 sequestration

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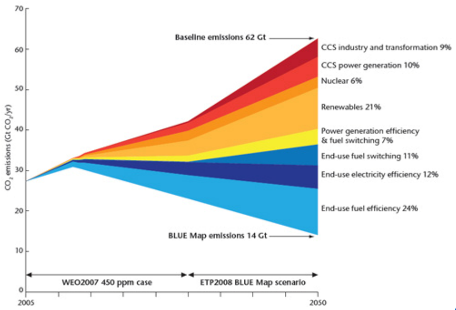
MUSTANG EC FP7, Collaborative Large Scale Integrating Project

1. CO2 capture and sequestration

Concentrations of atmospheric CO_2 have increased by more than 35% since industrialisation began[1]. Current global demand for fossil fuels is 80% of the total energy requirement. This cannot be met in the medium term by renewable energy.

To reduce the amount of CO2 entering the Earth's atmosphere from these increasing energy demands, Carbon Capture and Sequestration in deep geological formations is being considered.

CO2 is separated from industrial emissions and injected in its supercritical phase into suitable deep geological formations, where CO2 saturated fluids are sealed by impermeable caprocks overlying the reservoir sandstones.



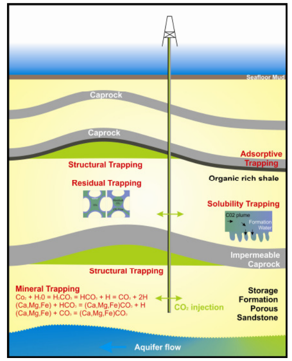
Source: IEA, Energy Technology Perspecttive (2008a)

2. CO2 sequestration

Injected CO2 is sequested in deep geological formations by a number of mechanisms:

Structural trapping - An impermeable caprock layer creates a barrier to CO2 flow.
Residual trapping - CO2 becomes disconnected and trapped by capillary pressure causing a trail of residual immobile CO2 behind the migrating CO2 plume.
Solubility trapping - CO2 dissolves readily into the formation waters leading to convective mixing where the denser CO2 saturated brine sinks.
Mineral trapping - CO2 reacts with the minerals in the geological formation to form stable carbonate minerals or compounds.
Adsorptive trapping - CO2 is adsorbed preferentially onto organic surfaces.

The interaction between CO2 and caprock may change the geo-chemical and geo-mechanical properties of the caprock, leading to changes in its permeability – **its integrity**.



3. THMC processes affecting caprock seal integrity

Thermal processes
Heat transport
Influence rock strength
Thermal flow
Solubility of CO2 decreases with increasing temperature

Hydraulic processes
Wettability
CO2 leakage if capillary entry pressure of caprock is exceeded
Single / multi phase flow
Capillary forces
Relative permeability
Phase change boundary
Interfacial tension

THMC coupled processes » caprock integrity
The individual THMC processes interact, influence and affect each other.
Quantifying and modelling these processes is crucial to understanding caprock integrity

Chemical processes
Dissolving CO2 in water » carbonic acid
Carbonic acid » forms bicarbonate ions
Bicarbonates » Ca, Mg & Fe to form solid carbonates
Evaporation into dry CO2 » salt precipitation
K-feldspar » kaolinite
Mineral dissolution » matrix weakening » permeability enhancement
Mineral precipitation » matrix strengthening » permeability reduction

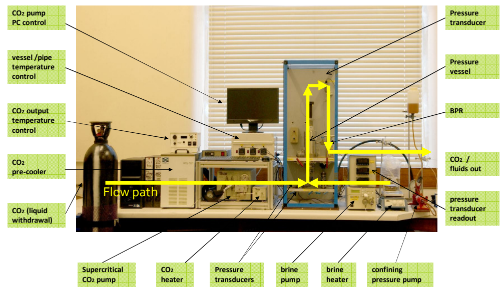
Mechanical processes
CO2 injection leads to changes in the mechanical stresses
Micro cracks initiated at phase change boundary
Existing faults/fractures may be re-activated
Pre-existing micro-fractures may be opened
Seismic activity
Fractures tend to open if aligned perpendicular to min principal stress (σ_3)
Fractures tend to close if aligned perpendicular to maximum principal stress (σ_1)

4. Geoscientific investigations – experimental equipment

Equipment facilitates exposure of caprock to CO_2 under realistic reservoir conditions of pressure and temperature where the THMC processes can be analysed.

The equipment (seen on right) can deliver:
Up to **69MPa (10,000psi) confining and fluid pressure**.
Up to **80°C fluid and rock temperature**.
Supercritical CO2 and brine fluid flow (single and multi-phase).
Upstream, downstream & differential **pressure measurement.**
Scope to add **tracers** (or other markers).
Uses **38mm diameter cylindrical rock** samples.

The experimental data is used as input and validation for coupled process numerical modelling undertaken in-house

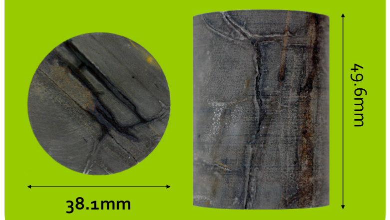


5. Analysis

Naturally fractured Kimmeridge Clay caprock samples from the Brae field from depths around 3600m downhole.

The fractured caprock was subjected to **supercritical CO2 flow of 1g/min at 40°C under increasing confining pressures from 20MPa to 65MPa** - No flow of supercritical CO2 was observed across the fracture even at a differential pressure of 36MPa (5200psi).

The system pressure and temperature was decreased to the **CO2 phase change boundary conditions** and very low CO2 gas flow through the fracture was observed.



Fractured Kimmeridge Clay sample

6. Results

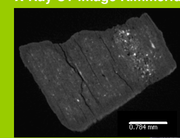
So far there has been very little reactivity of the caprock samples to CO2 exposure – this is good news for caprock integrity.

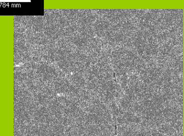
A couple of interesting reactions have occurred which will require further investigation.

The first is a possible reaction rim of lower density area on the outer areas of a caprock sample that was identified on the X-Ray CT scan. This could be associated with leaching by pyrite dissolution, no reaction rim was seen on the samples not exposed to CO2

There is the appearance of micro fractures within the matrix in one caprock samples exposed to CO2 only.

X-Ray CT image Kimmeridge Clay





SEM image Kimmeridge Clay

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[1] UK Met Office Data - www.metoffice.gov.uk/climatechange

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MUSTANG - A Multiple Space and Time scale Approach for the quaNtification of deep saline formations for CO2 storaGe www.co2mustang.eu