Imperial College London

Characterisation and use of polymer-gel solutions for CO_2 flow diversion and mobility control within storage sites

Sevket Durucan

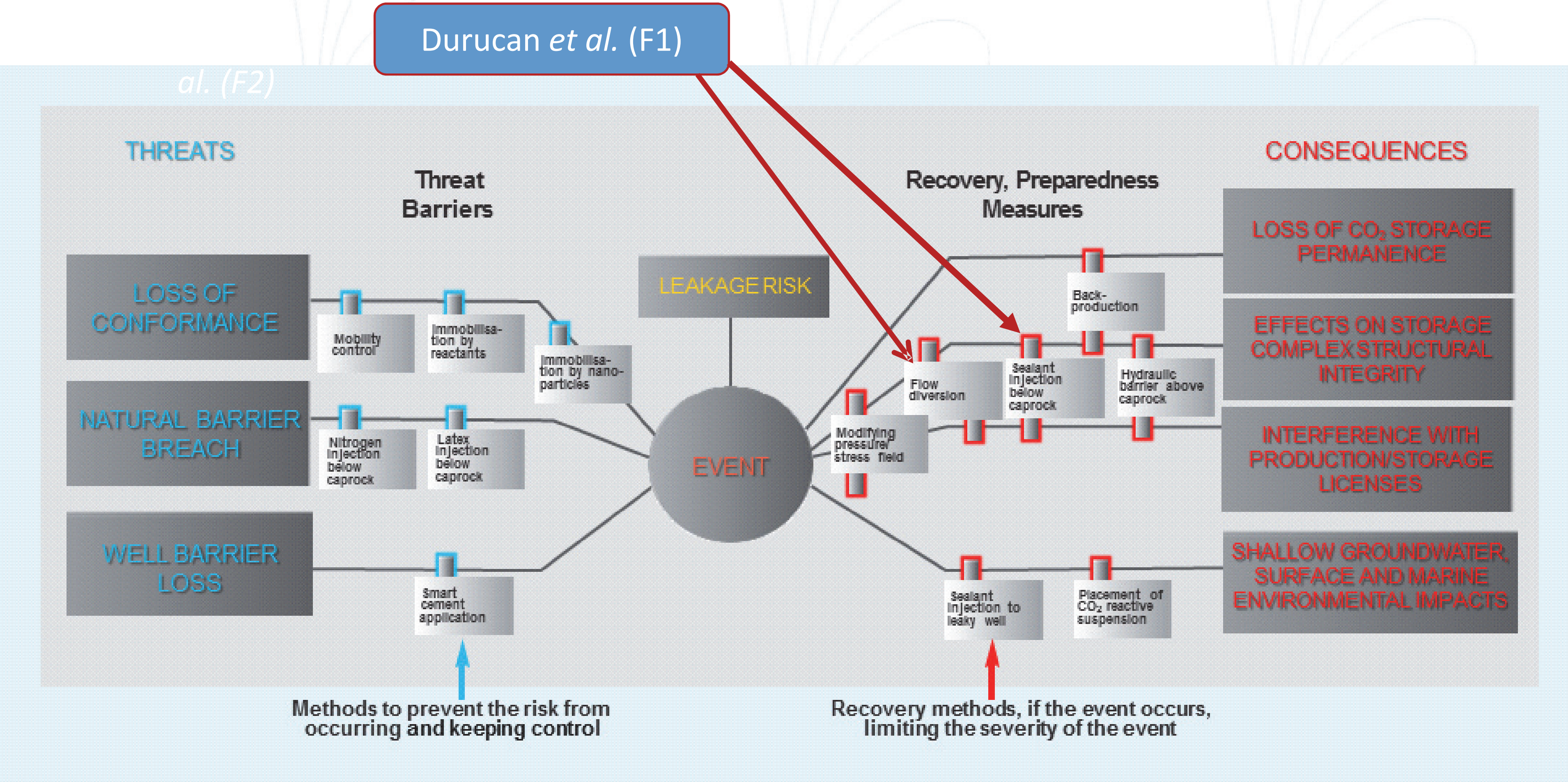
Anna Korre, Rajesh Govindan, Mojgan Hadi Mosleh, Ji-Quan Shi

Imperial College London, United Kingdom

minerals, Energy and Environmental Engineering Research Group
Department of Earth Science and Engineering
Royal School of Mines
Prince Consort Road
London, SW7 2BP

mERG

MiReCOL Mitigation and Remediation of CO_2 Leakage



Outline

- Introduction and objectives
- Experimental programme
  - Characterisation of polymer-gel solutions
  - Core flooding experiments
- Numerical simulation of field polymer-gel injection scenarios: Flow diversion and/or leakage remediation
- Conclusions

Motivation and Objectives

Motivation

- Knowledge of geology and petrophysical properties of saline aquifers is limited, i.e. there is significant uncertainty in the verification of CO_2 flow conformance.
- A corrective actions plan describing the measures to be taken in the unlikely event of CO_2 leakage is an essential requirement of a CO_2 storage site license application.

Objectives

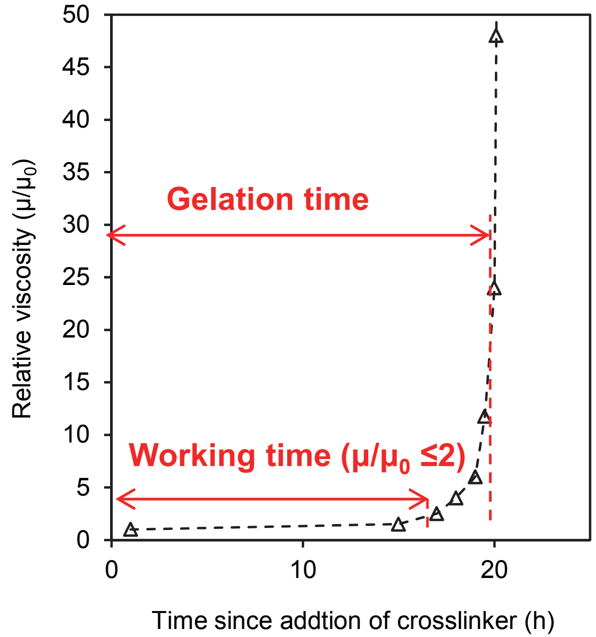
- To investigate the suitability of polymer-gel treatment to divert the flow of CO_2 and/or remediate leakage through
  - Laboratory characterisation of a number of polymer-gel solutions and their effectiveness in permeability control.
  - Numerical simulation of polymer-gel injection to assess their potential use for flow diversion or to remediate CO_2 leakage scenarios.

Laboratory characterisation of polymer-gel solutions

Polymer gel-systems tested

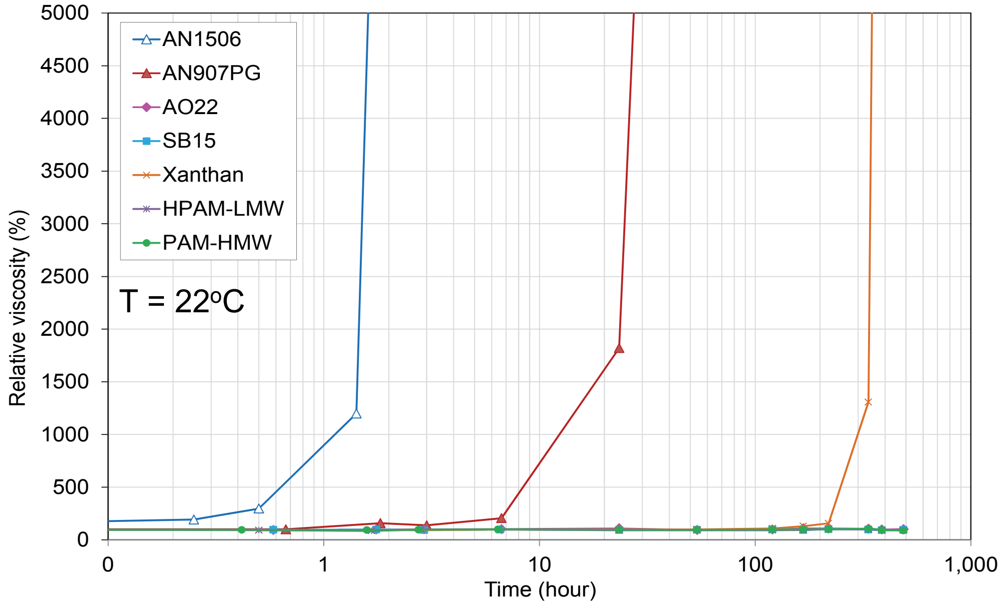
	AN1506	AN907PG	AO22	SB15	Xanthan	HPAM-LMW	PAM-HMW
		supplied by SNF Floerger, France				supplied by Sigma Aldrich, UK	
Polymer type	Poly-acrylamide-based	Poly-acrylamide-based	Poly-acrylamide-based	Poly-acrylamide-based	Poly-saccharide	Poly-acrylamide-based	Poly-acrylamide-based
Molecular weight	High	High	Medium	Medium	High	Low	High
Form	Powder	Powder	Partially hydrolysed	Partially hydrolysed	Powder	Partially hydrolysed	Powder
Base solution	0.5%wt NaCl in deionised water						
Temperature	22 – 60 °C						
Crosslinker	Tyzor 217: water-based zirconium chelate (Zr^+ content: 5.4%), supplied by SNF Floerger (Manufactured by Dorf Ketal)						

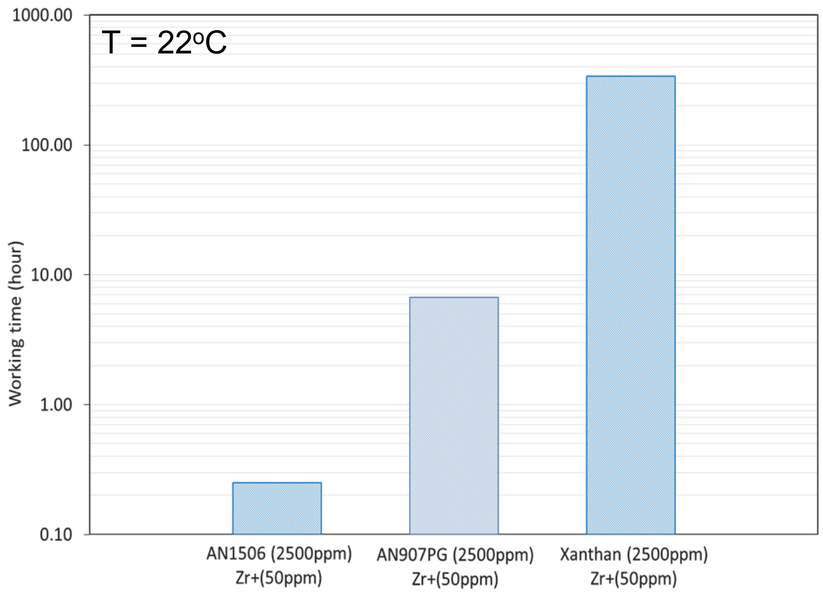
- Effect of polymer concentration on working times
- Effect of crosslinker concentration on working times
- Effect of temperature on working times
- Permeability reduction in core flooding experiments



Laboratory characterisation of polymer-gel solutions

- AN1506, AN907PG and Xanthan were crosslinked by Zr^+.
- Gelation times at 2,500 ppm polymer concentration, 50 ppm Zr^+ at 22 °C were:
  - AN1506: ~1.5h
  - AN907PG: ~28h
  - Xanthan: ~480h (20 days)
- AO22, SB15, HPAM-LMW and PAM-HMW did not produce gel even at much higher concentrations (up to 10%) and higher temperatures (up to 60°C).

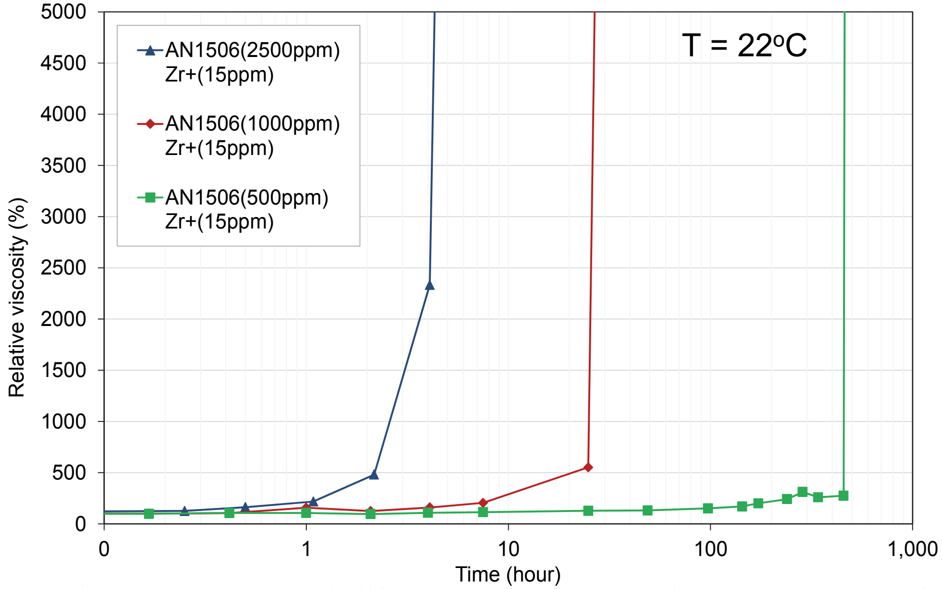


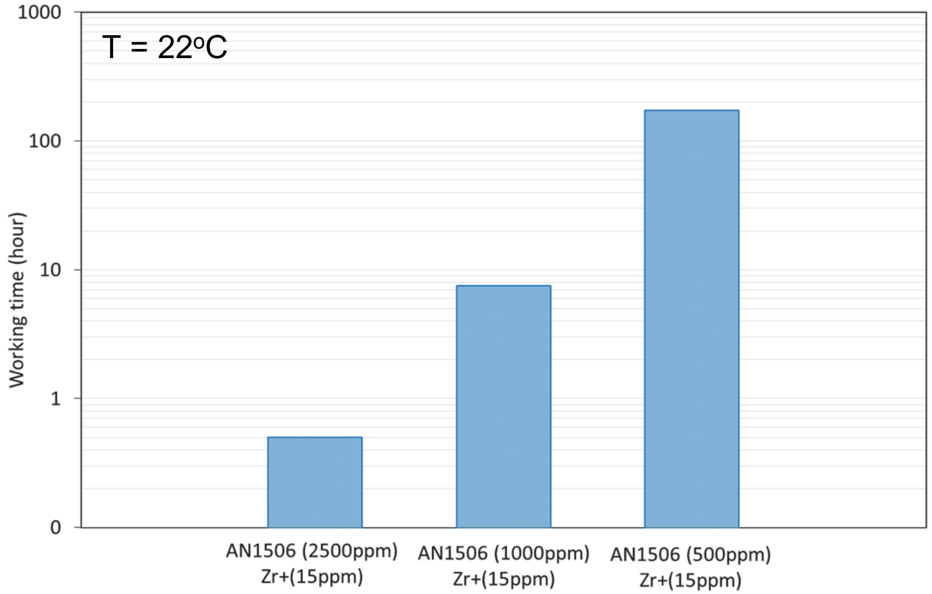


Laboratory characterisation of polymer-gel solutions

Effect of polymer concentration on working times

- Faster gelation was observed at higher polymer concentrations.
- For polymer concentrations <500ppm, only partial gelation was observed and the produced gel was found to be weak and uneven.

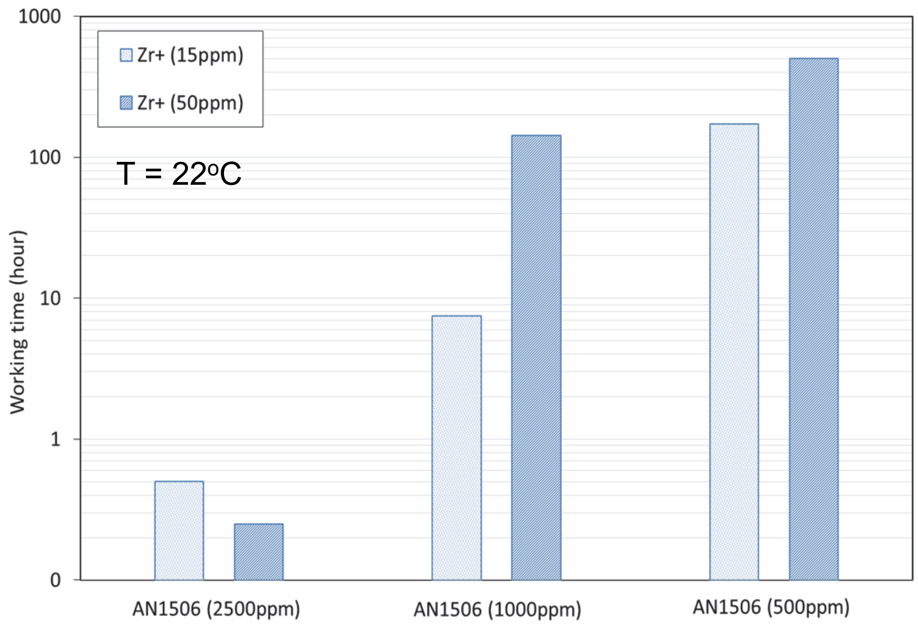




Laboratory characterisation of polymer-gel solutions

Effect of crosslinker concentration on working times

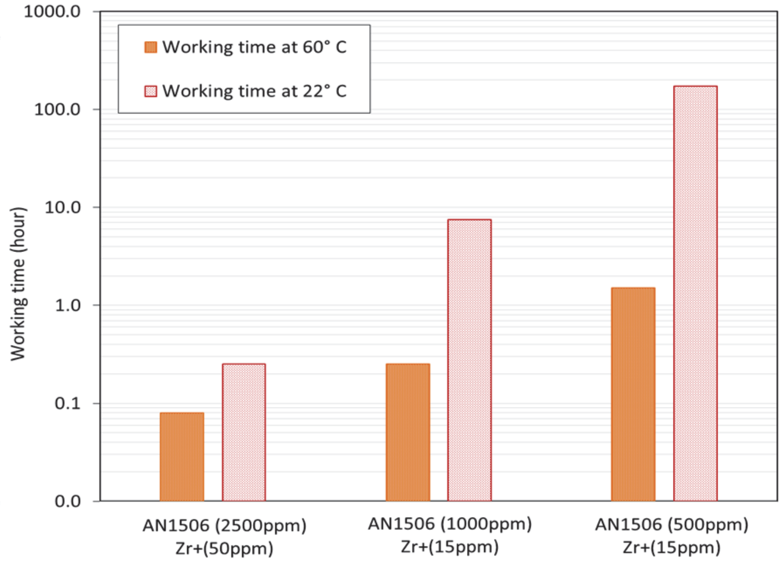
- The ratio of polymer-to-crosslinker (*P/X*) was found to be important in determining the gelation and working times.
- Polymer solutions with 1<*P/X*<10 did not undergo gelation, whereas those with *P/X*>10 were found to be more likely to undergo gelation.



Laboratory characterisation of polymer-gel solutions

Effect of temperature on working times

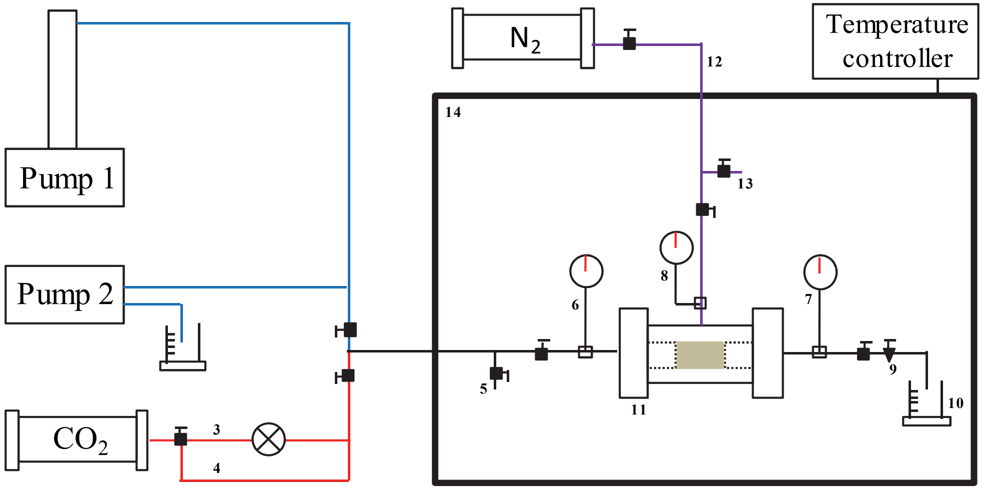
Polymer type	Polymer concentration (ppm)	zirconium concentration (ppm)	Working time (hr)	Gelation time (hr)
		at 40°C		
AN1506	700	15	4	22
	600	15	5	50
	300	15	No gelation after 168h	-
AN907PG	1,500	15	3	3
	1,200	15	No gelation after 144h	-
	700	15	No gelation	-
Xanthan	2,500	50	22	24
	700	15	1.3	4
	300	15	3	3
	100	15	No gelation after 144h	-
		at 60°C		
AN1506	2,500	50	0.08	0.4
	1,000	15	0.3	0.6
	500	15	1.5	partially gelled
	300	15	No gelation after 168h	-
AN907PG	2,500	50	0.5	1
	1,500	15	2.5	2.5
	1,000	15	No gelation	-
	500	15	No gelation	-
Xanthan	300	15	2.5	2.5



For higher concentrations of AN1506 and AN907PG, working time was significantly reduced with increase in temperature.

Polymer-gel core flooding experiments

Samples used: high permeability carbonate (Guiting) and sandstone (Doddington)



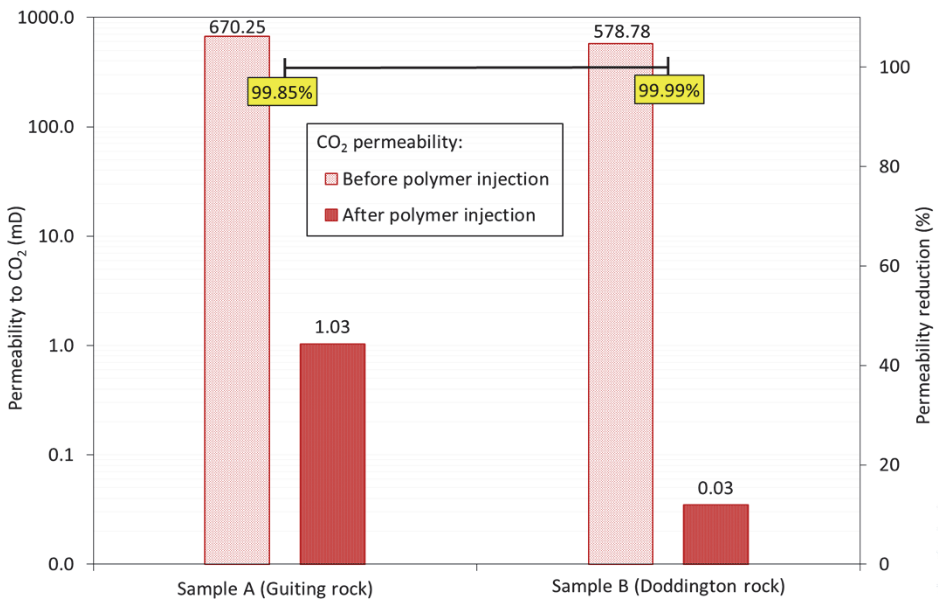
1: precision pump
2: continuous flow pump
3: flow controlled line
4: constant pressure line
5: cleaning line
6: inlet pressure transducer
7: outlet pressure transducer
8: confinement pressure transducer
9: back pressure valve
10: collecting beaker
11: Hassler cell with core
12: pressure confinement line
13: pressure release line
14: oven at 40°C

Procedure

- Samples saturated with brine (3%).
- Polymer gel injected into the core at constant rate (1mL/min).
- The system is isolated and polymer-gel in the pore space was left undisturbed to account for gelation time estimated from characterisation test.
- CO_2 was injected at constant pressure into the core sample to measure post-polymer injection CO_2 permeability and effectiveness of the polymer gel system.

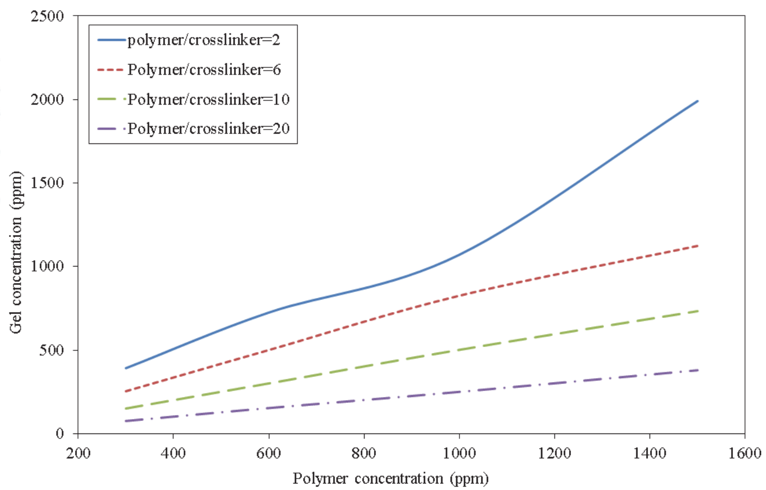
Polymer gel-core flooding experiments

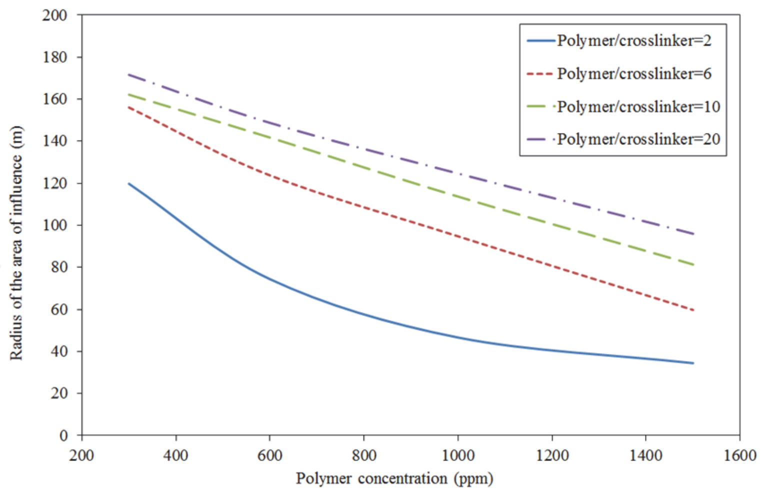
- A polymer-gel solution of 1,000ppm AN1506 and 15ppm Zr^+ was used for the core flooding experiments, at 22°C.
- For Doddington sandstone:
  - CO_2 Permeability was reduced from 578mD to 0.03mD (99.99% reduction).
- For Guiting carbonate:
  - CO_2 permeability was reduced from 670mD to 1mD (99.85% reduction).



The effect of polymer to crosslinker ratio on gelation

- Numerical modelling using the chemical flooding simulator UTCHEM 9.0
- A simplified homogenous reservoir at ~1,600m depth, dipping at 22^{o} was used to study gelation
- Simulation runs were performed for a range of polymer and crosslinker concentrations to assess the ***strength of gel*** formed and the ***area of influence***.



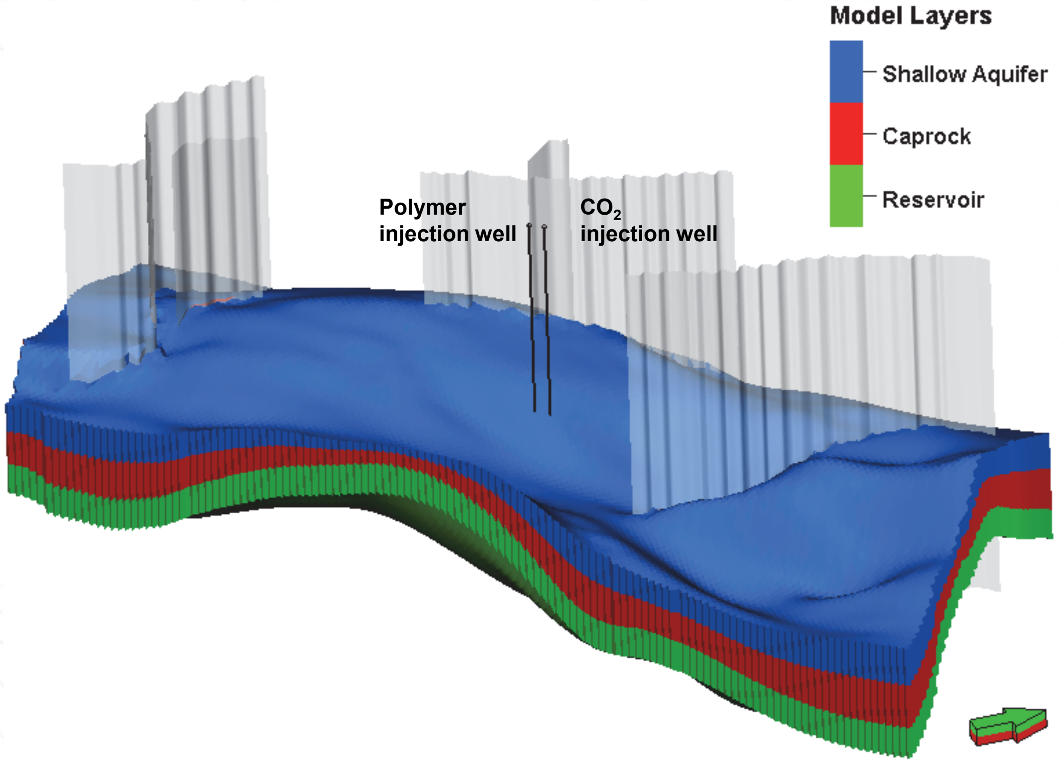


- Concentration/strength of the gel formed increased with increased polymer and crosslinker concentrations
- At lower polymer to crosslinker ratios a relatively higher gel concentrations are achieved
- The area of influence decreases with increased polymer concentration
- Lower crosslinker concentrations yield a relatively higher area of influence

Numerical modelling of field polymer-gel injection

The saline aquifer model

- A generic reservoir model was set up to study the mobility control of CO_2 plume and leakage remediation using polymer-gel injection in a heterogeneous saline aquifer.
- The structural model used in the study has a broad and considerably dipping anticlinal structure.
- The model grid spans an area of 36km×10km and includes five major sealing faults.



Reservoir:
- average thickness: 240m
- grid resolution: 200m×200m×4m

Caprock (seal) :
- average thickness: 225m
- grid resolution: 200m×200m×225m

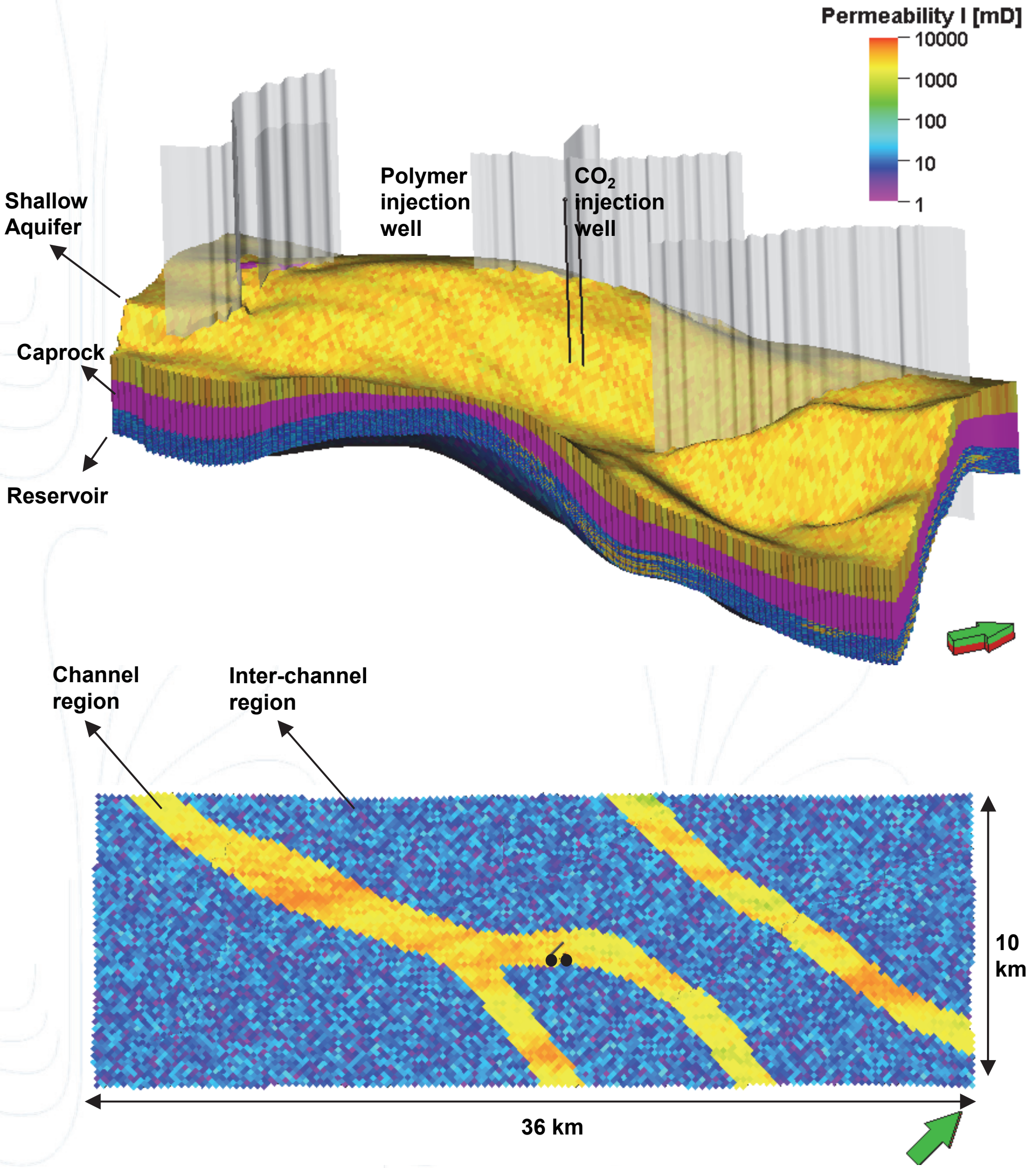
Shallow aquifer:
- average thickness: 175m
- grid resolution: 200m×200m×175m

The depth of the model ranges between -1,087m and -3,471m

Numerical modelling of field polymer-gel injection

The geological model

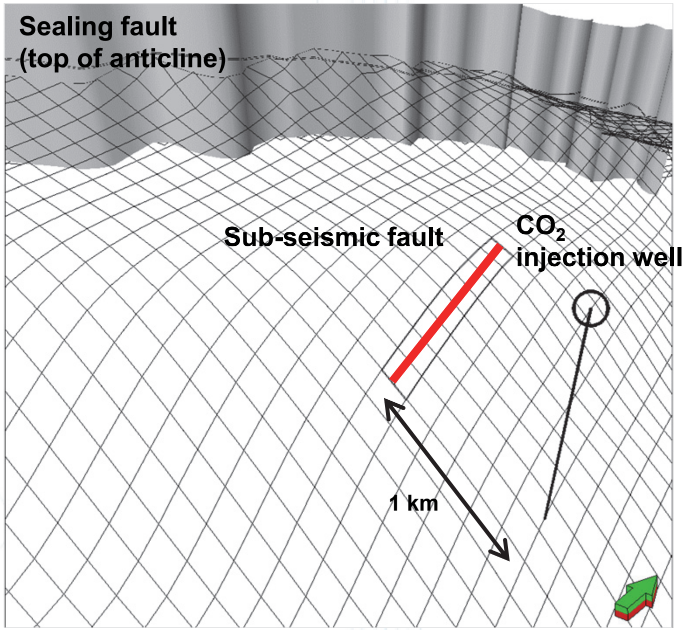
- The geological model represents a fluvial-channel system, typically containing braided sandstone channels and interbedded floodplain deposits (mudstone or siltstone).
- The petrophysical properties used in the model attribution are based on the Late Triassic Fruholmen Formation in the Hammerfest Basin, in the southern Barents Sea, located at depths similar to those considered in this study.
- The property attributions were generated using Sequential Gaussian Simulation (SGS) in order to represent the spatial uncertainty.



Numerical modelling of field polymer-gel injection

Model set–up and CO_2 injection

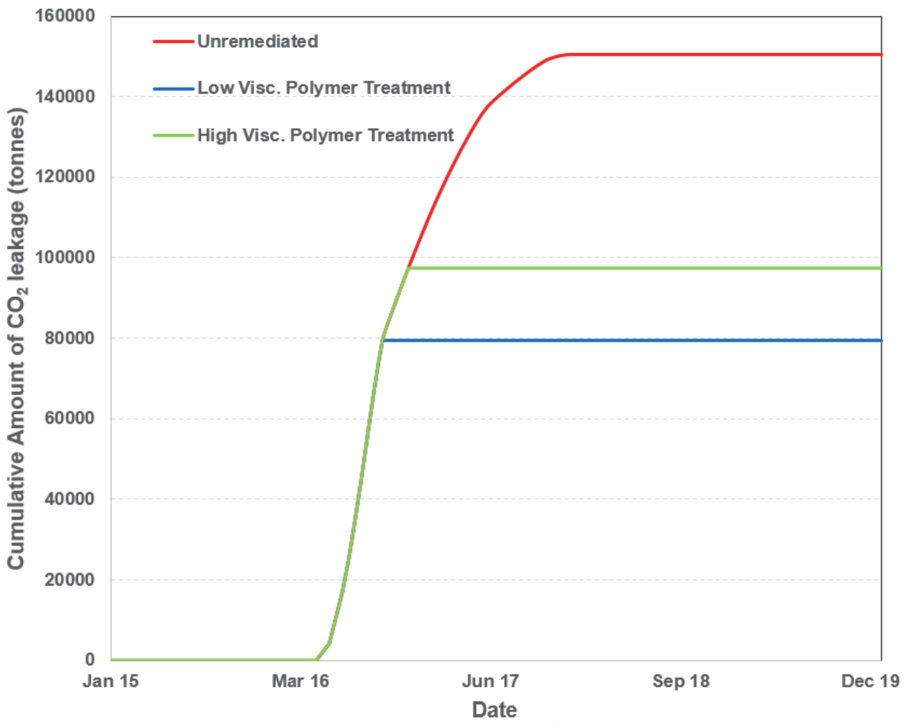
- A sub-seismic fault was introduced in the model at a distance of 1km away from the injection well, located at the flank of the anticline.
- A compositional flow model was setup in Eclipse 300 to simulate CO_2 injection at a rate of 1Mt/year.
- Leakage through the fault was detected inside the shallow aquifer after 1.75 years of CO_2 injection, considering 5,000 tonnes of mobile CO_2 as the lower limit for detection.
- CO_2 injection was temporarily terminated until polymer gel treatment in the reservoir was carried out.
- A number of scenarios were considered for the remediation of CO_2 leakage using low and higher viscosity polymer injection through horizontal well configurations.



- CO_2 leakage remediation was assessed during a total simulation period of 5 years.

CO_2 leakage remediation results

- The time period and amount of polymer-gel required to seal the leaky fault at the base of the caprock was assessed.
- After polymer-gel treatment, CO_2 injection was resumed for the remaining 5 year simulation period.
- Polymer-gel solution seals the fault and diverts the CO_2 flow as desired
- Remediated and unremediated cases were for compared
  - **Unremediated** case: the total amount of CO_2 loss from the reservoir without polymer treatment after the leakage was detected (160,000 tonnes).
  - **Remediated** case: the total amount of CO_2 loss until the start of polymer injection (80,000 or 100,000 tonnes for low and high viscosity polymer-gels respectively).



Conclusions

- Not all the polymers tested have gelled at simulated reservoir conditions.
- Laboratory characterisation work has indicated that as *polymer type*, *molecular weight*, *polymer and/or crosslinker concentration*, *ratio of polymer-to-crosslinker* and temperature has an effect on the gelation process and working time of the polymer-gel solutions tested.
- A reduction of more than 99% (2 - 4 orders of magnitude) was obtained in gas permeability at polymer concentrations of 1,000ppm, and Zr^{+} concentration of 15ppm in 0.5%wt NaCl.
- Numerical simulations have shown that the area of influence decreases with increased polymer concentration and lower crosslinker concentrations yield a relatively higher area of influence.
- Polymer-gel injection from a horizontal well close to the leaky fault can seal the caprock and remediate leakage.

Note: This is a shortened public version of a presentation made in Venice on 11 May 2016, further details can be found in recent and future publications by the Group.

Thank you very much for your attention!

Financial support by the **European Commission**

SEVENTH FRAMEWORK PROGRAMME

SINTEF

TNO innovation for life

GFZ Helmholtz Centre Potsdam

PRORES

Statoil

ifp Energies nouvelles

GDF SUEZ

The University of Edinburgh

Imperial College London

NIS Gazprom Neft