GAS INJECTION LABORATORY EXPERIMENTS ON OPALINUS CLAY
EXPERIMENTAL SET-UP AND PRELIMINARY RESULTS

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Abstract

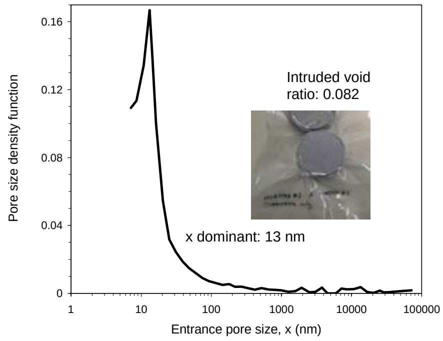
Understanding gas transport processes is one of the key issues in the assessment of radioactive waste repository performance and is the focus of this research. To this aim, this research programme was started with the following specific objectives. 1) To develop and calibrate an experimental set-up to perform controlled flow-rate gas injection experiments using a high-pressure triaxial cell to apply isotropic/anisotropic stress states. 2) To carry out a series of tests on Opalinus clay OPA samples to study the conditions under which gas breakthrough processes occur, to analyse the influence of the gas injection rate, the stress state, the orientation of rock discontinuities and other relevant hydro-mechanical variables (porosity, degree of saturation, …), as well as the observation of the induced desaturation (pore water displacement by gas), ingoing and outgoing gas fluxes, aperture and preferential paths created, and so on.

Tested material

Undisturbed OPA cores (dry coring and cast in resin) were recovered from 'MI niche' in the shaly facies and oriented normal to the bedding (Mont Terri Underground Rock Laboratory in Northern Switzerland). Samples were pre-cut under dry conditions with a band saw and then prepared with a lathe to match a circular cross-section with 50 mm in diameter and a maximum height of 25 mm.

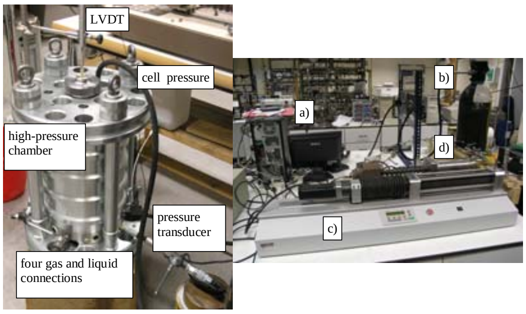
OPA properties

Density	around 2.34 Mg/m³
Density of solids	2.70 Mg/m³
Dry density	around 2.20 Mg/m³
Average void ratio	0.21
Average porosity	0.17
Water content	6.6% to 6.9%
Degree of saturation	around 90%
Total suction	15 to 57 MPa
Vert. water permeability	4.2×10^{-13} m/s
Estimated air entry value (dominant pore MIP)	22 MPa



Experimental set-up

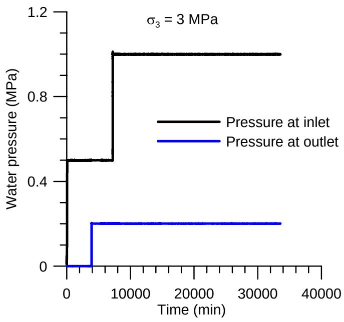
Each cap of the instrumented high-pressure triaxial cell has inlet and outlet lines, prepared for gas and liquid connections. The equipment uses four automatic pressure / volume controllers, two for gas (injection and extraction at downstream point), and two for water, which can be used in combination (for example, air injection and water pressure at downstream). The gas injection pressure / volume controller has a maximum range of 20 MPa (volume 500 mL), and is able to control volume rates between 10^{-4} mL/min and 100 mL/min (volume resolution < 5 mm³). The figure shows a picture of the developed triaxial cell jointly with the test set-up.

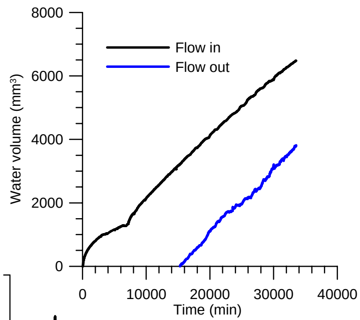


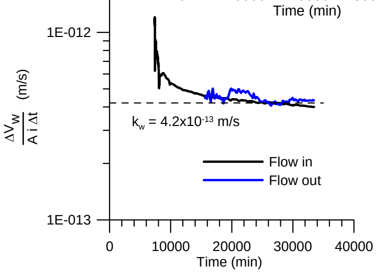
a) Data acquisition system
b) Pneumatic system with pressure regulators (confining and axial stress)
c) High gas pressure / volume controller VPC 500/200 Wille Geotechnik
d) Low gas pressure / volume controller GDS Instruments

Test results

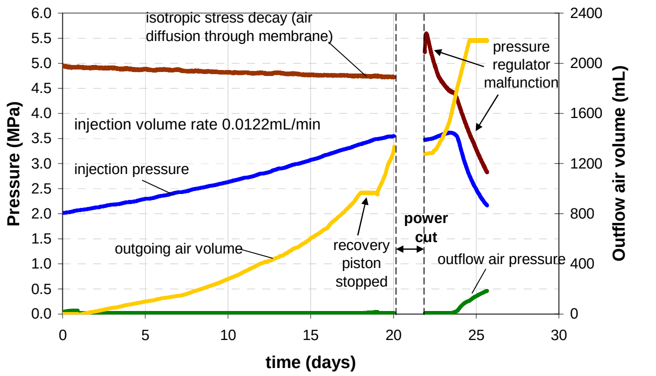
Saturation of the sample was ensured using controlled water gradient between bottom and top ends of the sample at constant isotropic confining stress (3 MPa). Increasing steps and ramps of backpressure (bottom) were applied up to a maximum of 1.0 MPa (see figure on the left). Top cap was maintained at 0.2 MPa. This last condition was maintained for more than one month to ensure approx. equivalent inflow and outflow liquid volumes (stationary flow conditions, as shown on the right hand figure). The water permeability of the material measured with inflow and outflow data was around 4.2×10^{-13} m/s, as indicated in the next figure (other references report 1 to 5×10^{-13} m/s).

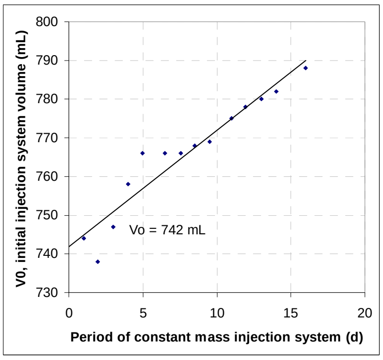






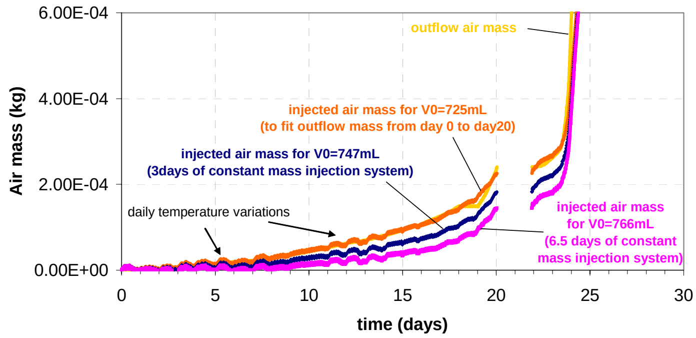
After saturation, the confining pressure was increased in a ramp to 5 MPa. More than one week was let to dissipate any excess pore water pressure to atmospheric conditions. Then, top and bottom water lines were drained. Starting from an initial gas pressure of 2 MPa, the bottom pressure of the air injection system was increased by using controlled volume rate: 1.22×10^{-2} mL/min. At around three weeks the pressure was at 3.5 MPa (as shown in the bottom figure). The top cap was maintained at 0.02 MPa. A power cut occurred after this initial period. Afterwards, confining pressure was restored by a pressure regulator, which malfunctioned (confining pressure decreased) and originated an injection pressure decay due to air passage between the neoprene membrane and the sample (air passage occurred at a difference between confining pressure and air pressure of 0.66 MPa)



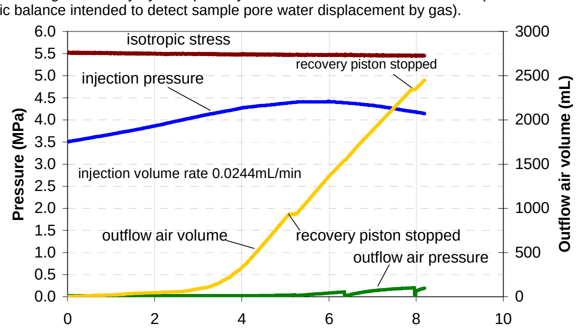


Fitting the constant mass system for different periods allowed estimating the initial injection volume of air (piston and air lines), as shown in the figure on the left.

On the other hand, deviations from the perfect gas law for a constant mass system in the injection point, allowed estimating the injected mass of air into the sample. The bottom figure plots the cumulative injected and outflow air masses.



Another air injection ramp using 2.44×10^{-2} mL/min was performed to increase bottom air pressure from 3.5 MPa to 4.5 MPa. Injection pressure was not able to increase over 4.5 MPa, probably due to incipient desaturation effects. The final degree of saturation will be estimated after dismantling. The next test will be carried out using a recovery system partially filled with a known mass of water (air / water interface and electronic balance intended to detect sample pore water displacement by gas).



time (days)

Acknowledgements

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