Hydro-thermo-mechanical behaviour of the Tournemire compacted shale (SE of France)

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Abstract A coupled flow process, thermo-osmosis, has been tested in the Tournemire shale, carrying a set of water changes by warmer one in a multi-packers system equipped borehole. Experiments interpretation with a hydrogeological model using coupled flow equations and thermal effects enables to propose a range of thermo-osmotic permeability.
Keywords thermo-osmosis; coupled flow; Tournemire shale.

INTRODUCTION

Clay rocks are considered in some countries as a potential host to high-level radioactive waste repositories. The benefits of considering such formations are mainly their containment and insulation natural abilities. Studies on these abilities especially require a full characterisation and quantification of mass transfer processes in these environments. Thermo-osmosis appears to be a process which can significantly affect fluid fluxes in compacted shales (Soler, 2001). However thermo-osmotic coefficients data in the literature are few (Dirsken, 1969; Shrivastava and Avasthi, 1975) and badly constrained as no *in-situ* experiments have been done, so far.

Thermo-osmosis is a coupled transport process which consists in a water flux under a temperature gradient while chemical concentration remains constant. The development of this kind of flux is related to the little pore size of indurate shales and to electrical forces field due to the surface charge of clay minerals. It confers membrane behaviour to the shale, by its ability to partially or fully limit the transport of certain ions and molecules. Thermo-osmosis phenomenon appears because of specific enthalpy differences of water in the boundary layers and pores (Derjaguin *et al.*, 1987).

In the geological context, we can observe temperature gradients at the basin scale due to the regional geothermal gradient or to heat-generating radioactive waste or, during repository galleries excavation (leading to a local modification of the regional geothermal gradient).

THERMO-OSMOSIS EXPERIMENTS

We have carried out *in-situ* thermo-osmosis experiments on the Toarcian shale of Tournemire (SE of France) which presents analogies with rocks likely to host a radioactive waste repository. This formation forms part of the *Grands Causses* Mesozoic basin and is studied at the French Institute for Radiological protection and Nuclear Safety (IRSN) Underground Research Laboratory (URL) located at Tournemire. This URL consists in a century-old tunnel crossing the Toarcian shale and more recent galleries excavated from the tunnel. The shale is characterized by very low porosities (around 9%), hydraulic conductivities (10^{-13} to 10^{-15} $m.s^{-1}$) with a small mean diameter pore size (4-6 nm) and by electrical surface charges (given by a cation exchange capacity about 10 $meq.100g^{-1}$).

Experiments have consisted in substituting the water in equilibrium with the formation by a warmer one (temperature increments of 2.5, 5 and 9°C) for inducing a potential thermo-osmotic response. Those experiments were performed in a multi-packers system equipped borehole limiting a small test interval (20 cm^3). A special attention was paid for the substitution of the test section water under initial and stabilised pore pressure.

HYDRO-THERMO-MECHANICAL MODELLING OF THE EXPERIMENTS

Pressure evolution in the test interval after the water change shows a rapid decrease, followed by a stabilisation after 1.5 days. Next the pressure tends to increase, very slowly (Figure 1). We have managed to reproduce the signal by introducing the different expected phenomena in our model.

Experiments were interpreted with a 2D finite differences thermo-hydro-mechanical model based on coupled flux equations combined with mass conservation laws (Gonçalvès *et al.*, 2004), and by adding thermal and thermo-osmotic effects. Thermo-osmotic coupled flow equation can be written:

$$U = -k_T \cdot gradT \qquad (1)$$

where U is the filtration velocity ($m.s^{-1}$), kT is the thermo-osmotic permeability ($m^2.s^{-1}.°C^{-1}$) and grad T is the temperature gradient ($°C.m^{-1}$).

Once the hydraulic properties of the shale were determined, we simulated an aquathermal effect (Luo and Vasseur, 1992) and changes in water properties (viscosity and density) with temperature (Figure 1). This can account for pressure changes related to water during the temperature dissipation in the shale after the water substitution. In Figure 1, two curves simulate the thermal effect and limit a range of evolution as a function of the measured system compressibility range. Compressibility appears to be the most sensitive parameter of our model when thermal aspects are introduced.

Next, we identified an additional effect explained as thermo-osmosis by fitting the model prediction to the measured data by using a range of thermo-osmotic coefficients (Figure 1). However, due to the obtained compressibility range, we are only able to identify a range of thermo-osmotic permeability.

The same methodology was conducted for the three temperature increments (2.5, 5 and 9°C) tested during the different water changes.

Results given by fitting give a range of thermo-osmotic permeability between 4×10^{-11} and 6×10^{-10} $m^2.s^{-1}.°C^{-1}$ as a function of the temperature increment (Figure 2). These values are in the range of thermo-osmotic permeability obtained in previous experiments (Dirsken, 1969; Shrivastava and Avasthi, 1975). We also observe a decrease of thermo-osmotic permeability inverse to the temperature increment.

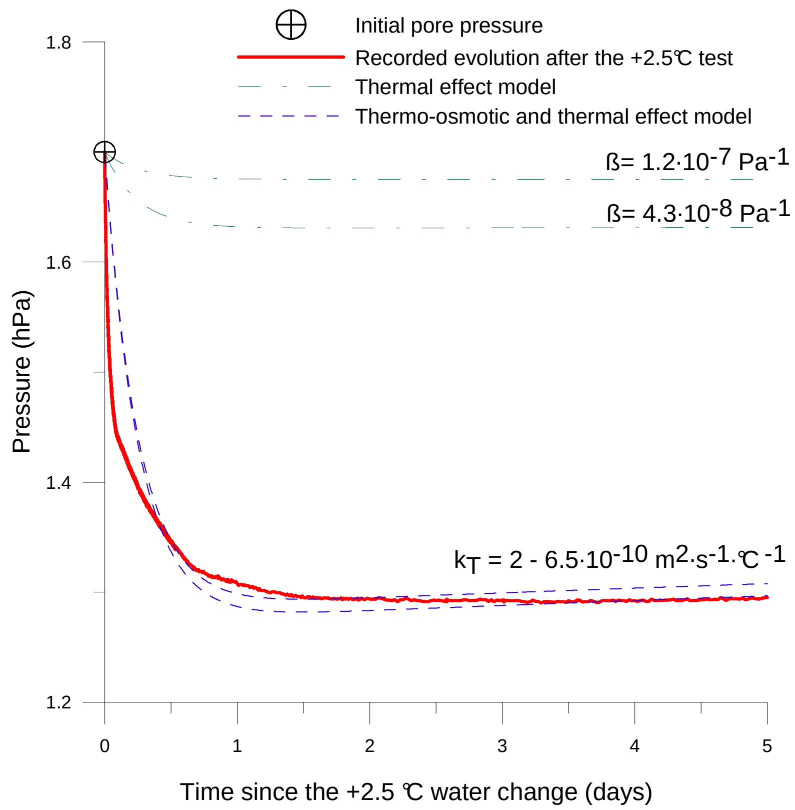

Figure 1 Measured and modelled pressure evolution after the +2.5°C water change test.

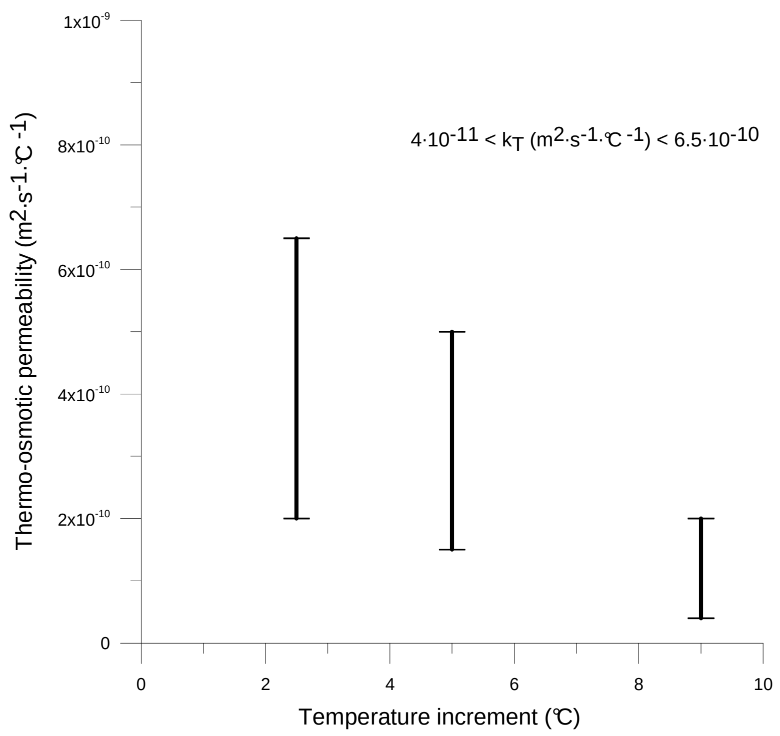

Figure 2 Thermo-osmotic permeability obtained for different temperature increments applied during the water changes.

CONCLUSIONS AND PERSPECTIVES

In-situ water changes by a warmer one experiments performed in the Tournemire shale and their interpretation with a model integrating coupled flow equations have given rise to a thermo-osmotic effect, which has been quantified. In order to reach a more narrow thermo-osmotic permeability range, we are trying to better constrain sensitive parameters in our modelling.

Thermo-osmotic effect will next be coupled to chemical osmosis, hydraulic advection and other processes, like changes in boundaries hydrodynamic conditions and effect of tectonic compression. The goal of this modelling is to identify the transport phenomena at the origin of overpressures observed in the Tournemire shale and their respective contribution (Matray *et al.*, 2007).

REFERENCES

Derjaguin, B. V., Churaev, N. V. and Muller, V. M. (1987). *Surface forces*. Consultants Bureau, New York.

Dirsken, C. (1969). Thermo-osmosis through compacted saturated clay membranes. *Soil Science Society of America Proceedings*, **33**(6), 821-826.

Gonçalvès, J., Violette, S. and Wendling, J. (2004).Analytical and numerical solutions for alternative overpressuring processes: Application to the Callovo-Oxfordian sedimentary sequence in the Paris basin, France. *Journal of Geophysical Research*, vol. **109**, B02110, doi:10.1029/2002JB002278.

Luo, X. and Vasseur, G. (1992). Contributions of compaction and aquathermal pressuring to geopressure and the influence on environmental conditions. *American Association of Petroleum Geologists Bulletin*, **76**(10), 1550-1559.

Matray, J. M., Gonçalves, J., Savoye, S., Girardin, I., Cabrera, J. and Lecathelinais, P. (2007). PH4: a 250m deep borehole in Tournemire for assessing the contribution of transport phenomena to assumed overpressures in the Toarcian/Domerian semipermeable. *3rd International Meeting on "Clays in Natural & engineered barriers for radioactive waste confinement"*, September 17-18, Lille, France, 409-410.

Shrivastava, R. C. and Avasthi, P. K. (1975). Non-equilibrium thermodynamics of thermo-osmosis of water through kaolinite. *Journal of Hydrology*, **24**, 111-120.

Soler, J. M. (2001). The effect of coupled transport phenomena in the Opalinus Clay and implications for radionuclide transport. *Journal of Contaminant Hydrology*, Vol. **53**, 63-84.